W. E. Wood

WESTERN AUSTRALIAN INSTITUTION

OF

ENGINEERS.

PROCEEDINGS.

VOLUME 3.

No. 1.

NOVEMBER, 1912.

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PRESIDENTIAL ADDRESS.

(By Ernest Edward Light.)

I rise with feelings of deep gratitude to the members of this Institution for the honor done to me in electing me as their third president. It is the greatest honor they can confer and I assure them that I will devote myself to maintain the prestige and to promote the interests of this Society with the important profession to which we belong.

It is the usual custom of societies of this kind, at the first ordinary meeting of the yearly session, for the president to deliver an address, and I do not think I can do better than to confine the matter to one of the principal engineering transport agencies which are necessary for the development of this State of Western Australia. Your first president, Mr. James Thompson, in his inaugural address, described the early means of transport by roads constructed principally with prison labor. But it was not till 1871 that it was proposed to build railways. The first railway in the colony was built and owned by private enterprise, and was laid down from the coast at a spot some five miles to the north of

Busselton, and generally known as Lockeville. This line was constructed to bring jarrah logs from the Darling Range, some 20 miles distant, to a saw mill at Lockeville, and was completed in 1871. The location of the railway was rather peculiar in that it apparently was not laid out with a theodolite, as there are long swings in the alignment, as if it had been set out by a ganger, and occasionally a tree got in his way, so he put in small angles of deflection, the angles ranging from 21 to 30 minutes. The gauge is 3′ 6″.

I made the acquaintance of this railway in 1885, when I was engaged in surveying an extension for the timber company, and at that time the rails were in such bad order that the heads were in many places gone entirely and the wheels were running on the web, the traction power being horses, although there was a locomotive in a shed at the coast—said to be the first manufactured in Australia, at the Phoenix Works, Ballarat, Victoria—but I understood if it went out on the road it might be necessary to send a team of bullocks to bring it home. I may say the locomotive is still at Lockeville. The greatest engineering difficulty I noticed on this line was crossing a large swamp or chain of swamps a few miles from the coast. This was surmounted by constructing a low flood timber opening probably half a mile long. The original rails were iron and weighed, I believe, 21 lbs. to the yard. The line was out of use for many years until the rails were replaced in 1898 with 45, 46¼ and 50 lbs. steel rails. As the jarrah was intended for export, a small jetty was constructed from the mills into the sea, and sailing vessels loaded direct.

The next railway was built in 1872—also constructed by private means—and is known as the Jarrahdale Timber Company's line from Rockingham to the Darling Ranges at Jarrahdale.

This line was also constructed to carry jarrah to the coast for shipment, but after it was sawn at the mills at Jarrahdale. The gauge is also 3′ 6″. The original rails were wood with iron strips on curves.

The line has been extended beyond Jarrahdale and additional mills erected, and is still working, but is connected to the Government railways at Mundijong, and that portion from the latter place to Rockingham is now never used. The greatest engineering difficulty on this line was getting through the Hills with as little earthworks as possible, and this was accomplished by putting in sharp curves of 3 chains radius. I understand it is contemplated to flatten these curves shortly, as a deviation has been pegged out.

In the third line constructed we have a change of ownership. This is the Northampton line—the first railway constructed by the Government. This line was first proposed, I believe, in 1871, and authority was received from the Imperial Government (this State was at the time a Crown Colony).

The object in building the line was to bring down lead ore from the Northampton mines to Geraldton for export, the mines being 25 miles from Geraldton; and the line as constructed was 34 miles in length. The survey for the line was let by contract to a Melbourne firm, who sent an officer to carry out the work in 1873, but as lead had dropped in price the construction of the line was deferred, and it was not until 1879 that it was completed. When the contractor took possession of the ground he found the pegs had been eaten by white ants, and the alignment was in many places located by himself, hence some reverse curves were of $3\frac{1}{2}$ and 4 chains radius without any straight between. The ruling gradient was 1 in $35\frac{1}{2}$, and weight of rails 35 lbs. to the yard and of iron.

The rolling stock was necessarily of a light class, the axle load of the locomotive being 5 tons 15 cwt. only, and that on the tender; on account of the sharp curves, two engines of the Fairlie patent were introduced, but were not satisfactory, and one was afterwards cut in two and made into two small shunting engines.

Some two years ago the line was relaid with 45 lbs. steel rails and the sharp curves deviated and flattened, and eight chains radius is now the sharpest, and the length of the line was reduced by 34 chains.

A noteworthy fact to be remembered is that the sleepers, which were 6″ x 3″ in section, were well preserved. The line was opened in 1879 and the majority of the sleepers were still fit for use in 1909, showing that they were well selected from mature timber and free from heart. This is an object lesson.

Now we come to a line of more importance than all of them—the first step in the Eastern Railway and in fact the general railway system of the whole State—from Fremantle to Guildford. This was really the forerunner and parent line of many others, and was constructed under the authority of the Crown Government, and was opened in 1881. The rails were steel, $46\frac{1}{4}$ lbs. to the yard and the ruling grade 1 in 60, the sharpest curve being 15 chains radius.

It is apparent that there must have been a battle of the routes for this line, as surveys were made in 1874 on both sides of the river between Fremantle, Perth and Guildford, and there were many proposed crossings of the Swan River. The first survey for any part of the Eastern Line was made from Guildford towards Greenmount in 1873; therefore, the idea at that time must have been to make Guildford the western terminus, and make use of the river to Perth and Fremantle, as goods for the York district were lightered from the ships in Gage Roads at Fremantle and conveyed per river to Guildford, thence per road.

An old wharf and crane were only recently removed from the northern end of Meadow Street, known as Barker's Bridge.

The special features of this section are the two bridges over the Swan River, one at Fremantle and one at Guildford. Both were constructed of jarrah.

The timber had been well selected, as it has stood the thirty odd years—especially the piles—remarkably well. The Fremantle bridge was duplicated in 1895 by the Public Works Department for the construction of the harbor, and the piles have had to be renewed already. This section was extended to Chidlow's Well, some 21 miles, in 1883, the location passing near Mr. Smith's timber mill; hence the name " Smith's Mill " station.

A short distance on the Perth side of this station difficulties cropped up: a cutting was in progress and the slopes, which consisted of pipe clay full of water, were continually slipping in, and the contractors appealed to the Government for a deviation, and after some consideration one was set out which brought the formation 17 feet below the bed of the creek and on the same alignment; consequently a large diversion of the creek followed, some of the water being turned through another valley which led into the Helena River. The trouble was not over now, for when the new cutting was taken out the bottom was also pipe clay and springs of water, with the result that after the rails were laid and a train passed over, the rails and sleepers were invisible, in fact the bottom was so soft that the late Inspector Hayden on stepping off the Permanent Way once went down to his arm pits and was rescued with difficulty by the aid of a rope. To try and cope with the difficulty a layer of large stones or boulders were laid down, but these went out of sight; then timber baulks were laid longitudinally under the sleepers, but these disappeared; then the contractor tried an experiment by laying bundles of rushes and brushwood, unknown to the departmental engineer, on the formation, but these followed the stone and timber. It was then decided to put down some bores, and at a depth of some 33 ft. solid rock was touched, but among the cores which were brought to the surface from the boring tubes, to the astonishment of the departmental engineer, were green rushes from the bottom, and the gentleman in question reported to his Government that rushes were growing at a depth of 33 ft. below the surface! The result of finding a bottom was that a wall of sheet piling with walings was driven down to the rock on each side of the Permanent Way, and it was tied together at the top under the base of the cutting with wrought iron tie rods, the result being that after a drain was taken out on the outside of the sheeting the centre portion was kept fairly dry, and it has stood since that time. There is always a fairly strong stream

running from each side all the year round. The grade through this cutting is 1 in 22, and therefore limits the load of trains to a very small tonnage on this section.

From Chidlow's Well the line was extended to York and Beverley, with branches to Northam and Newcastle (now Toodyay). All these sections were laid with 46¼ lbs. rails and 7′ x 8″ x 4″ sleepers.

About the time these latter sections were constructed, 1885 to 1888, the Geraldton-Walkaway line (19 miles) and the Bunbury-Boyanup line (15 miles) were also built, the former with 46¼ lbs. rails and the latter with 35 lbs. rails. The former was laid in connection with the concession to the Midland Railway Company, as the Government provided that the terminus of the concession line should be some 20 miles on a Government railway from the sea ports at both ends—thus the Government could carry all their traffic for 20 miles, whether imported or exported.

This completes all the Government lines constructed while the State was under Crown control, with a total of 200 miles.

In 1890 the Colony was granted Responsible Government, and about this time the great discoveries of gold were made some 250 miles east from Fremantle, and it was decided to extend the railway system from Northam to Southern Cross, and later to Coolgardie and Kalgoorlie. The usual battle of the routes took place, and Northam and York fought hard for the honors of the starting point, but the former won, and thus formed what is now called the Eastern Goldfields Line ; although, according to the present programme, York will have its direct connection at Merredin *via* Quairading. Since this time the steel rails have been creeping north, east and south, to the total mileage of 2,506½ to-day with 324 in actual construction, and 711 are owned by private companies or used in connection with various industrial undertakings, making a grand total of 3,541 miles.

Included in this is the deviation of the Eastern Line between Bellevue station and Chidlow's Well, known as the Mahogany Creek deviation. This was constructed to reduce the grades between those stations from 1 in 30 and 1 in 22 to 1 in 50, and includes the only tunnel in the State used for railway purposes. In other places on the Eastern Line the grades have been improved and curves flattened, all tending to reduce working expenses. Also 106 miles of line have been duplicated and the main lines have been relaid with 60 lbs. rails, permitting the running of heavier locomotives thereon, which means heavier trains and further reduction of working expenses.

In 1884 an agreement was signed between the Government and the W.A. Land Company to build a line from Beverley to Albany, the Goernment giving land along the line and the company building the line.

This was opened in 1889, but the Government purchased the line and land not taken up in 1896. The ruling grade was 1 in 55 and sharpest curves 15 chains radius.

Another railway was also built on the land grant system by the Midland Railway Company of Western Australia, from Midland Junction to Walkaway. The first sod was turned at Midland Junction in 1886, but there were many delays in carrying out the work, from financial causes, and the line was not opened for through traffic till 1895. The ruling grade 1 in 60, and sharpest curve 15 chains radius. Since all these railways have been constructed their usefulness has been increasing, and their help to develop this great State has been very marked, and the traffic has increased to such an extent that the line and rolling stock have been improved and strengthened to a considerable degree—577 miles which were originally laid with 46¼ lbs. and 45 lbs. rails have been relaid with 60 lbs. material and heavier sleepers. And 50 miles of 35 lbs. rails have been relaid with 45 lbs. material, and bridges have been likewise strengthened to carry heavier rolling stock, which has had to be increased in weight and carrying capacity, and more powerful locomotives employed. All this has tended to decrease the cost of working expenses. The last five years it having decreased from 66.16d. to 58.82d. per train mile equal to 8.34d., and from £748 to £532 per average mile of railway worked, equal to £216.

Regrading of the lines is also another saver of working expenses, and much has been done in this direction, ruling grades which were 1 in 45 have been reduced to 1 in 60 and 1 in 65, and 1 in 60 to 1 in 80, and at the present time are being reduced on the suburban line from 1 in 80 to 1 in 100. This allows an increase in the load of trains with the same locomotive power and consequently reduces the number of trains and increases the value of the railway as an earning machine. The reduction of existing grades is all very fine and interesting and serves well to show how easy it is, when done, to reduce working expenses ; but what should be borne in mind when designing and laying out a new railway is the best possible grade to be obtained, and what the working costs of that grade are going to be. Especially so is this necessary where light rails and narrow gauge are being made use of. If the grades are high when the line is constructed and it afterwards becomes necessary to reduce them to deal with the traffic, then money has to be spent, as all this work must be done while trains are running, which you can easily understand means high prices. Given an easy grade to commence with, there will then not be so much necessity to relay with heavier permanent way or to use heavier engines.

Among the improvements to locomotives is most noteworthy the Garratt type of engine, which is so constructed that it is capable of negotiating sharp curves with ease, has a very large proportion of its wheels

effective, making it possible to have a big tractive force on a light rail; and last, but not least, a grate of greater width and thereby reducing the length.

Among the minor improvements to the permanent way, in addition to laying with heavier rails and sleepers, is the introduction some nine or ten years ago of the spring frog crossing. This gives a continuous rail for the main line and makes, in addition to smoother running, a considerable saving in wear and tear. Another improvement is the putting in of short point blades into the K crossing of double compounds where worked by interlocking levers. This system, which has been in use some seven or eight years, also ensures smoother running and saves wear and tear, but the greater security of trains passing over same is of far more importance. These switches are operated in connection with the main switches of the compound.

I would here point out the wise proceeding of each of the two timber companies who constructed the first railways in the State adopting the same gauge, and then the Government also following suit, as since the extension of the State lines the two timber lines have been connected thereto, which has enabled the rolling stock to run right through.

Had the whole of Australia adopted the same policy and followed one gauge what a lot of trouble and inconvenience would have been saved and later on expense, as ultimately I hope to see one gauge only on this Continent or at least not more than two—as instead of the State of Western Australia laying a second gauge from Kalgoorlie to our western coast the money could have been spent in duplicating the existing line for that portion, and the public getting the advantage of shorter time in travelling between East and West.

In speaking of our present gauge, where the average speed is 25 miles per hour: with 80 lbs. rails and proportionally heavier sleepers and better class of ballast, with improvements in the curvature and grades on a double line, the average speed might well be brought to 32 or 35 miles per hour. Such a service would be equal to if not better than any long distance one in Australia.

It must be apparent that although we have in this State a gauge of only 3′ 6″, that a very useful railway has resulted, the coaching stock is very little narrower than that of the 4′ 8½″ or 5′ 3″ gauge in operation in the Eastern States, and it is no doubt very suitable to a young colony which is struggling to get its lands and productions developed with the minimum of cost.

The late Mr. J. F. Thallon, Commissioner of Railways in Queensland, was very enthusiastic in regard to the 3′ 6″ gauge as a medium for developing a new country, and to express his views I cannot do better

than to quote from his report to the Queensland Government after his tour through Canada, Great Britain and South Africa in 1908, the following :—" The developments of the 3′ 6″ gauge on all the railways in South Africa are truly marvellous, and as that gauge is more flexible, and costs much less to install in mountainous country such as we have between Brisbane and Sydney, I think Queensland was well advised in adopting it in the first instance."

I would here invite any member to read a paper on the advantages that would accrue by adopting any gauge either in this State or for the whole of Australia.

There is another railway, which is in its embryo state at present but which will interest us very shortly, and that is the Trans-Continental line, which will be constructed by the Federal Government, from Kalgoorlie to the Eastern border of the State, to connect to Port Augusta, in South Australia. It is provided to build this line on 4′ 8½″ gauge, and I understand it is the intention of the State Government to build a line of a similar gauge from Kalgoorlie to Perth and Fremantle. We do not know whether the route has yet been decided upon, but it is hoped that it will be one which will give the best grade and not be undulatory—that is to say, the load will not be dragged to the top of a hill and then dropped down again over the other side to rise again in gaining the summit of our Range. There is likely to be much controversy over its location around and between Perth and Fremantle, and it is to be hoped that any member of this Institution who has thought about this matter will be ready to express his ideas either in a paper to be read at one of our meetings or any way he may think best, as I am sure the Government would welcome any suggestion from which a satisfactory scheme could be worked out.

Before I conclude I would like to follow in the footsteps of my immediate predecessor, Mr. Past-President Leslie, and say a few words in reference to the education and training of engineers. The subject has undergone a vast amount of consideration and argument in Great Britain of late years, and only last June a conference took place at the Institution of Civil Engineers, London, when such eminent men as Sir John Wolfe Barry and Mr. Alex. Siemens, the then President of that Institution, took part in the discussion, the results of which was the following proposal, which was not moved as a resolution :—(1) That the Council of the Institution be desired to use its influence in any way deemed practicable to secure a continuity of study between those public schools where the elements of science are taught, and the universities and technical colleges so that pupils leaving such public schools may be suitably trained to follow at once a college course with advantage, so that, as it were, the college course may begin where the school training finishes ; (2) that with a view to facilitate the above, a closer connection between the masters

who teach science in public schools and the Institution of Civil Engineers is desirable ; (3) that the Council of the Institution should endeavour to induce the universities and technical colleges to adopt such terms of study, say, six months during the winter, that the sandwich system can be adopted, if desired, which is not possible with the terms now customary ; and (4) that it is desirable that the Council should endeavour to produce some co-ordination between the colleges and the employers by making a systematic inquiry from the employers as to the conditions under which exceptional students properly qualified may be able to get practical training for a period of, say, 24 to 36 months on the sandwich or any other system when vacancies in such establishments occur.

You will see it was plainly laid down at that conference that practical training must be given in conjunction with theoretical training, and the weight of evidence showed that it was better to give the pupil the practical portion sandwiched with the theoretical—assuming that he had been well grounded in mathematics, trigonometry, chemistry, etc., before he left school.

Gentlemen, I have much pleasure in opening the third session of our Western Australian Institution of Engineers, and trust that we shall have a good and successful year.

THE TRANS-AUSTRALIAN FEDERAL RAILWAY.*

Considered in Regard to its Approaches through Perth and Fremantle to Cockburn Sound.

(By James Leonard.)

I have chosen as the subject of the paper, I now have the honor of reading before the Institution, a matter of practical interest of to-day so far as our State of W.A. is concerned. We have passed the borderland of ephemeral reports, and have now to face the materialistic consideration of this Federal Railway, in its dual aspect; which pertains, first, to the purely Federal view, regarding it as an arm of defence, as emphasised by Lord Kitchener a few years ago; and secondly as a Commercial railway, on which its future as a paying proposition must depend. There is reason for grave consideration in this second direction. Speaking as an Engineer I wish to avoid trenching on political ground as much as possible. Our business is to carry out instructions, but I feel sure that engineers will agree with me, that we need not sink the ship in striving to carry out our instructions.

As regards Fremantle, that Port (the future Brindisi of Australia,) might receive otherwise meritorious treatment, if it deserved it. Fremantle has spoken, through its Port and Civic authorities, in unmistakable terms on this matter. The extension of the Commercial Harbor of Fremantle must come up the river. Those obstructive, out-of-date bridges, must come down and out of the fairway. It is a matter of congratulation, that, even at this late hour, the Port and the City of Perth, have arrived at so happy a consummation of feeling in their mutual interests.

The planning of modern cities has only lately been added to the burden of accomplishments of the 20th Century engineer, who is usually not credited with much superfluous possession of the aesthetic sense. At first blush, this seems somewhat a harsh remark to add color to; but, when we look around the glorious monuments of architecture that ancient cities abound in, and claim that their architects were also engineers, we simply focus the mind on a plane of differentiation, leaving to our architects their well-deserved honors for their creative sense of artistic beauties, while we, of grosser mould—practical engineers of the pick and shovel, are humbly content with our share of the commercial common sense, the business of the people.

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*The Plans and Section illustrating this paper may be seen at the Rooms of the Institution.

Our Australian cities are comparatively of mere mushroom growth, but in their evolution we see the making of Australia, the youngest of the white nations of the great British Empire. In this respect of preconceived design, our Federal Capital to be, has had every advantage over the State Capital cities, Brisbane, Sydney, Melbourne, Adelaide and our own Perth, which though the youngest of the group, may by virtue of her geographical position lay claim to some degree of pre-eminence. Our State's march of progress has attracted the attention of the world over seas, and this Federal Railway of Australia will replace with bands of steel the so-called crimson threads of kinship among our own State.

In regard to the engineering features of the origin and growth of Perth, I cannot do better than refer members to the able and informative address by our first President, Mr. James Thompson, at the inaugural opening of our Western Australian Institution of Engineers, on March 31, 1910. My paper is chiefly concerned with the Railway environment of our City and Port, to which I must now confine my remarks, with many apologies for the pre-ambulatory introduction. I feel that I cannot do better than plunge into the middle of things, leaving all matters of controversy to a future time, when, metaphorically speaking, I can imagine myself being trodden on by wild horses.

I have chosen as the point where the alignment enters the city, the road level of the Mt. Lawley subway with the Eastern Goldfields Suburban Railway passing above it. This point will be the zero or 00 in reference to dimensions of length. All R.Ls. (reduced levels) are taken from the contour plan, and have reference to dimensions of height above the zero of the Fremantle Tide Gauge, which is the State's Ordnance Datum for sea level. Mount Lawley subway is at R.L. 47, which for practical purposes, I have fixed as the rail level of the Federal Railway entering the city. The bottom of girder flange carrying the Eastern Goldfields Railway, is at R.L. 62. This allows fully 15 ft. of head clearance for the Federal Railway to pass under. The width of Mt. Lawley subway between abutments, which are on the skew, is 29 ft. 9 in., so that there is room for a double line of 4 ft. 8½ in. gauge to pass through. The Board of Trade regulations allow 14 ft. 6 in. for head clearance, and 24 ft. 4 in. for side clearance, in Great Britain. The German Railways allow 15 ft. 9 in. for head clearance, and 24 ft. 6 in. for side clearance. The French Railways allow 14 ft. for head clearance and 26 ft. for side clearance. These are all on the 4 ft. 8½ in. gauge, double line. It should be noted that I have provided for a double line right through the city. This should be the rule right through the Metropolis from Midland Junction to Fremantle, and thence to Cockburn Sound, the naval base of W.A. In the matter of head clearance, in passing under or over all objective points, I have fixed 18 ft. from rail level to rail or road level as the limit of clearance. This provides fully 15 ft. of girder-bottom-flange clearance plus 3 ft. of girder depth of web to upper rail level.

The effective depth of girder is ample, though of course girders of 5 to 6 ft. depth may be used for extra strength and parapet divisions. In every case, on the proposed alignment, it will be seen that the minimum cover cap for clearance and strength, is either available, or can easily be made so.

While on these technical, though all important trivialities, I take the opportunity of stating that where the proposed alignment is on the street, its centre line is mathematically along the centre line of that street. The reason for this is as follows :— Our streets are mostly 66 ft. wide from building line to building line. If we take a central strip of 24 ft. for the minimum of railway formation, as masonry revetment in either cut or fill, or as piers for elevated railway, we have left a width of about 20 ft. on each side of the Railway for a roadway between building line and railway parapet. The kerb footpath would need to come out, and the roadway made right across between building line and Railway parapet; so that on each side of the railway there would be sufficient room for road traffic, with suitable subway or overway crossings at short intervals along the Federal Railway. The guiding features of this class of railway location have been closely studied in the selection of alignment, grade, and curvature in this matter. It is a pity that we have not wider streets to engineer in, but the objection is not a fatal one. We have a double line of tramway cum-roadway in Hay-street, which was pronounced legally not to be a " street " at all. The same remark may apply to Fremantle High Street.

We must now rapidly traverse the alignment. Leaving Mt. Lawley subway the alignment follows along the old Guildford Road, taking up, as before said, a minimum railway formation width of 24 ft., and providing a roadway of about 20 ft. on each side of the railway. The grade from 00 to 200 is level. At 200, Park Road comes in from Mt. Lawley on the west. Park Road would have access to Mt. Lawley existing railway station on the north, but not across the Federal Railway to West Parade on the south. It would also have an approach along the old Guildford Road parallel to the railway on the west.

From 200 to 600 the grade is 1 in 83. At 600, Walcott-street comes into Old-Guildford road but does not cross it. Walcott-street has two easy approaches, one northwards to Mt. Lawley railway station, and another southwards along Old-Guildford road west of the Federal Railway. From 600 to 700 the grade is still 1 in 83 to the existing level of the Old-Guildford road. At Walcott-street there is a curve, which should have its radius determined (within the limit of curvature) so that the secant of the curve should fall on Old-Guildford road, an easy matter to do, at that point. We should naturally close up any approach northwards from Oxford-street along the intrados of that curve on the

east roadway strip of Old-Guildford road, because there would be no place for the approach to go to, the Mt. Lawley subway being altogether taken up by the Federal Railway.

From 700 to 936 the grade is 1 in 80.61. Oxford-street takes off on the west of Old-Guildford road but does not cross it. The rail level here is 4 ft. above the road and Oxford-street has an approach southwards to Norwood-street. Masonry Parapets only needed.

From 936 to 1275 the grade is still 1 in 80.61. Harold-street enters Norwood-street on a level crossing, the rail level there being 0.44 ft. above existing road level. Divert the road traffic along both sides of the railway. Masonry parapets only needed here.

From 1275 to 1650 the grade is still 1 in 80.61. At 1650 Cantle-street crosses into Turner-street. The rail level here is 14.80 ft. above the road level which can further be lowered, if needed, to provide sub-way crossing under the railway with 18 ft. clearance. The Old-Guildford road on each side may be graded to this subway, up to which the railway would be masonry revetment in filling from 1275 to 1650 ft. a length of 375 ft. The subway would have a width of 50 ft. for the road traffic.

From 1650 to 1950 we reach where Broome-street crosses into Chap-man-street. Here the railway would be elevated on piers still preserving the grade of 1 in 80.61. The span could be from 25 to 30 ft. as being the most economical. Between such spans under certain regulations, shops could be placed and a source of revenue thus provided. Elevated railway 10 spans of 25 ft. 10 spans, 10 shops.

At Broome-Chapman-street, the rail level is 13.5 ft. above road. A subway at once suggests itself to preserve the right-of-way. The level of subway would be lowered so as to give head clearance of 18 ft., and the road approaches graded accordingly.

From Broome-Chapman-street subway the railway grade falls 1 in 249.1 from 1950 to 3350. At 2,325 ft., Marlborough-street on the east, no crossing is needed, and the alignment curves westwards with 20 chains radius. This street has approaches northwards and southwards on the east side of the railway. Before reaching Marlborough-street there would be 9 spans of elevated railway, where more shops could be fitted in, the road being graded accordingly. At 2,700 ft Lincoln-street comes in on the west. The present terminus of the Lord-street tram-line (single) is on the south building line of Lincoln-street on the Old-Guildford road Lincoln-street does not cross the railway, but is naturally diverted northwards along the Old-Guildford road parallel to the railway.

From 2700 to 3350 at Wright-street the railway, on the easy grade of 1 in 254.5 and curvature of 20 chains radius continues in easy cut and fill to R.L. 63, where rail level, is only 1 ft. above road level, which could

be closed or diverted but no level crossing permitted under any consideration. Level crossings in a populous city are a positive nuisance, a menace to safe traffic for both rail and roadway, and a constant source of anxiety to the railway traffic authorities.

From 3350 Wright-street to 3750 the centre of Padbury-street, the railway would run practically on street level, and only masonry parapets would be needed. From 3750 the railway still continues level, while the road grade falls, so that this bit would require about 7 ft. of revetment in filling from 3750 to 4100, when the elevated railway in Padbury-street would begin. The object is of course to keep the railway high enough in air, so as to clear Stirling-street and Beaufort-street, to allow those two most important arteries of the city to pass underneath the railway with the limit of head clearance of 18 ft.

From 4100 to 4500 along Padbury-street would be elevated railway on piers, 16 spans of 25 ft. each, where more shops could be placed. Rail level R.L. 63 on level grade.

From 4500 to 4600, Stirling-street would be cleared, providing a subway of 17 ft. head clearance for that magnificient street northwards, but unfortunately ending in a miserable "cul-de-sac" at present.

From 4600 to 5050, still on a level grade at R.L. 63 would be elevated railway, 18 spans of 25 ft. each, where more shops could be placed.

From 5050 to 5150, still on a level grade at R.L. 63, Beaufort-street and its double line of tramway would be cleared. Here Brisbane-street would be entered.

After crossing Beaufort-street it is necessary to bring the Railway to earth again on the centre line of Brisbane-street. From 5150 to 5870 along Brisbane-street the determining grade of 1 in 90 falls from R.L. 63 to R.L. 55, near the west building line of Lane-street, where earth is reached.

From 5870, near the west building line of Lane-street R.L. 55 is the determining level, which may be continued absolutely level along Brisbane-street in easy out and fill for 3330 ft. for the railway station site. This could be well placed fairly in the middle of that length, with due regard to the approaches from the north as well as the south of the City. The railway station site would be between 5870 and 9100. In this connection the land resumption contemplated, if necessary, would be all that piece of land colored red on plan, bounded on the north by Bulwer-street, and on the east by Beaufort-street, on the south by Brisbane-street, and on the west by Fitzgerald-street, comprising an area of about 50 acres, and involving a cost of about £65,000, based on the annual ratable value of improved land. The number of tenements would be about 300, necessitating the shifting of a population of about 1,200. This ought to afford an additional incentive to the philanthropic policy of "homes for the working classes." Though the cost of this land resumption may seem

enormous, we may cut it down in another direction by at least 20 per cent., or £13,000, as the value of the material of demolition, which would be readily saleable in these days of progress, or applied to fill up those unhealthy Chinese gardens in the very heart of the city.

From 9100 to 10750 the railway would continue in cut and cover, still on the level grade at R.L. 55, and a curvature of 20 chains radius. We can hardly call this alignment a tunnel, but the high contours encountered serve admirably to find cap to pass the railway underneath the several streets that converge there.

First Cowle-street at 9350, road level R.L. 65, rail level R.L. 55, in 10 ft. of cut. Pass Cowle-street over the railway with 15 ft. clearance, or close it up altogether.

Second, the junction of Charles-street, Leeder-street at 9175. Road level R.L. 90, rail level R.L. 55. There is 35 ft. of difference providing ample clearance for tunnel cap.

Third, under Charles-street alignment at 10,000. Road level again R.L. 90 and rail level R.L. 55. There is again 35 ft. to provide clearance for tunnel cap.

Fourth, and the most important, Newcastle-street whichcarries adouble line of tramway, and is therefore one of the chief arteries, east and west, of the city. Here at 10,525, the road and tram rail level is R.L. 68, and the Federal rail level is R.L. 55 or 13 ft. lower. It is easy to find head clearance of 15 ft. to bottom flange of girder, by raising Newcastle-street or we may grade the tunnel a foot or so below R.L. 55 at that point. No difficulty at all.

After emerging from cap and cover on the Charles-street alignment at 10750, the Federal Railway has to negotiate the super-passage of our suburban railway, at the eastern extremity of the present West Perth railway station. The grades therefore again rises 1 in 80 providing subway at 11,225, Charles-street and John-street with 17ft. head clearance. On this 1 in 80 grade from 10750 to 11225 the railway formation would be in revetment in filling. After Charles-street and John-streets, the railway still on 1 in 80 grade goes to Charles and James-streets, as elevated railway from 11225 to 11625, with ample head clearance of about 27 ft., and providing 14 spans of 25 ft. each for shops in between. After Charles and James-streets subway, the railway goes on to Charles and Roe-street, still on 1 in 80 grade, elevated railway, providing subway of 32 ft. at Roe-street and 12 spans of 25 ft. each for shops in between James-street and Roe-street at 11975.

From 11975 Roe-street, to get across our suburban railway the Federal Railway passes above it near the eastern end of West Perth railway station. to the south building line of Queensbury-street at 12200. The head clearance is expressed thus :—Existing suburban rail level at West Perth is R.L. 53. Proposed Federal Railway level in air is R.L.

71. Difference—18 ft. The super-passage would be on level grade at R.L. 71, for a length of 225 ft.

We are now making for the tunnel still with an eye to the objective points of street crossings. The determining grade of 1 in 80 now falls, but is still favorable. From 12200 to 12900 the alignment is not on any street, but is elevated railway over the houses on Government resumed land, until Marquis-street and Wellington-street crossing is reached. The elevated railway between would provide 26 spans of 25 ft. each for shops. Where the important crossing of Marquis and Wellington Streets comes in, the Federal Railway is 14 ft. above the road level there. Lower the street crossing a couple of feet to provide the necessary head clearance for a proper subway there. Still on the falling grade of 1 in 80 after Wellington-Marquis-street subway, the Federal Railway touches earth again at 13200, before it enters the tunnel. After 13200 the next objective point is at 13350 where George-street comes into Murray-street. At this point the contour level is R.L. 70, where the Federal rail level is R.L. 56.62, that is 13.38 ft. under the road crossing. The alignment of the railway, it should be noted, keeps off George-street so as to avoid any unnecessary conflict with the storm water drain that runs under that street, by a very safe margin of 100 ft. to the west of that street, and considerably above it in R.L. It is an easy matter to pass Murray-street over the Federal Railway with 18 ft. head clearance, as the fall of the country there provides most favorable contours. I have weighed these points most carefully, and have arrived at the conclusion that an engineer would not be justified in deviating in alignment to improve the ruling grade if 1 in 80, with the tunnel approach looming up before him, and Hay-street yet to be passed.

The tunnel face is reached at 13600. From Murray-street super-passage, the approach to the tunnel would be in open-cut revetment depth with an average of 16 ft.

From tunnel face at 13600, owing to the configuration of the contours there, it seems to me reasonable to continue the 1 in 80 grade falling into the tunnel for a short distance, so as to pass under Hay-street and its double line of tramway with a sound cap. The drainage question has also been considered, and the tunnel has been graded so as to drain from its south or river side tunnel face, northwards, and then into George-street drain, where the levels would be most favorable for receiving the tunnel drainage to pass it into the river, both during the construction of the tunnel, and its permanent installation. These points are shown on the longitudinal section. The tunnel would have a length of 2650 ft. from face to face, or about half a mile. Between Malcolm and Mount-streets I have provided a tunnel station of 600 ft. platform length, for the convenience of members of Parliament. This tunnel station will have a road approach also in tunnel along and under Mount-street of a

length of about 700 ft. which would be graded with a slight fall outwards for drainage purposes, and so that the approach would be very easy for motors, cabs and horses. At Malcolm-street end of the platform a lift has been provided for the special use of members of Parliament. These double approaches by road, tunnel and lift should serve for visitors to the beauties of King's Park, and are eminently suitable for ventilation purposes. The tunnel emerges into Cliff Gallery on the west side of Cliff-street, and an easy curve of 30 chains radius guides the alignment along the approach to the bridge across the Narrows. From a careful inspection of the dip and strike of the sandy limestone strata along the King's Park cliffs, the geological conditions are ideally perfect for tunnel construction rapidly and cheaply, would be required to prove this statement. The river tunnel face is at 16250, and at 16500 the cliff gallery begins at R.L. 60. The grade of the tunnel is 1 in 300, which is within the limit of station requirements for trains to stand at the platform, without brakes on.

Cliff Gallery from 16500 to 18125 at Mounts Bay road abutment of the river bridge. This will be at R.L. 60 on a perfectly level grade. Built on light graceful lines of strengh in re-inforced concrete in spans of about 30 ft., the structure could be made aesthetically chaste—a poet's dream in Arabesque tracery—so as to relieve the dull olive sombre aspect of that beauty spot, as seen from Perth waters.

The Narrows bridge from 18125 to 18225, 1 span of 100 ft. and 3 spans of 200 ft. each. From a study of the nature of the borings for foundation of piers, I am gladly forced to the conclusion that it would be better to put the 3 spans of 200 ft. into 1 span of 600 ft., which would cost a little more money. There would be no trouble in finding safe foundations. for the piers to carry the superstructure at a depth of 10 to 15 ft. below the river bed, and in making these foundations absolutely safe. The headway provided would be fully 37 ft. above L.W.M. or ordinary spring tide, and 35 ft. above H.W.M. This would be ample for such pleasure craft as the Zephyr and Westralian, or even for the type of steamer that cruises about the pleasure resorts of Sydney's beautiful Harbor. The type of bridge I propose, is familiar to engineers. The upper or compression booms would carry a double line of rails at R.L. 60. The lower or tension booms would carry at R.L. 40, or 20 ft. lower underneath the railway, a double line of tramway cum-roadway and sidewalks. The width of the bridge would not need to be more than 26 ft. or such a width as close economic design would admit of in composite lattice girder construction. The lattice type is suggested as lending itself to graceful light construction, combined with great strength, and so as to offer the least area of surface to wind pressure. At Mounts Bay Road provision is there to pass this road under the bridge, while at the same time a branch takes off from the road and climbs in easy grade of 1 in 40 to R.L. 40, at which level it enters the Narrows Bridge with a double

line of tramway and roadway combined. The south approach of the bridge does not go to terra firma of South Perth, but along the foreshore, on the west of that ideal suburb, where we have the beautiful Zoological Gardens, with which should be incorporated the future Botanical Gardens. Foreshore reclamation works for South Perth, badly needed, could be cheaply provided the debris of tunnel excavation, supplemented where necessary by dredging operations along the foreshore. There would be room for baths, regatta clubs " et hoc genus omne," all a source of profitable revenue. At Frenchman's Bay glorious visions of wealth in riverborne traffic suggest themselves—the Wapping Old Stairs of London. But all this is beyond the scope of this paper, which must stop after the Narrows have been bridged. From there the railway alignment to Fremantle is a clear business. The land has been acquired, a good route surveyed, and everything preparatory to salvation has been done. The estimate subjoined, Schedule A. and B. provides only for work to be carried out from 00 at Mt. Lawley subway to 18825 end of bridge across Narrows.

I had intended to say a few words about the estimate in regard to the rates adopted, but this matter had better be left for future discussion. My estimate has considered the fact that labor charges have advanced fully 20 per cent. within the last few years and that there has been a corresponding rise in the price of material in all cases. Still the estimate will be found to be within fairly safe limits on the high side. Any room for economy must be looked for in structural design, and the strict limitation of requirements with a view to later expansion. It is impossible for me to say within a few thousands what such a scheme is going to cost, considering the short time I have had to devote to this matter in some undetermined factors. Here the words of the immortal Shakespeare, sparkling with appropriate metaphor and engineering advice, should apply forcibly to our present position of perplexity or uncertanty in this matter.

" When we mean to build,
We first survey the site, then draw the model,
And when we see the figure of the house,
Then must we rate the cost of the erection,
Which, if we find, outweighs ability,
What do we then, but draw anew the model
In fewer offices, or at least, desist
To build at all."

In conclusion I have to express my best thanks to Mr. James Thompson, Engineer-in-chief of W.A., and to several of his officers for their kind assistance, without pledging themselves to the case. I am also indebted to my friend Mr. G. T. Poole, who has always taken a keen interest in the city planning of Perth from the engineering as well as from the aesthetic standpoint. Let us hope that all efforts in this direction may soon come to fruition.

SCHEDULE A.

Approximate Estimate.

Double line 4 ft. 8½ inch gauge. Length 18,825 ft.=3·56 miles—3m. 45ch. 23 lks.

Chainage From.	Chainage To.	Length Feet.	Particulars of Formation.	Rate. £	Unit. Z	Estimate £
00	700	700	Revetment in cut. Average ht. 3 ft. ...	3		2,100
700	1,275	575	Masonry parapet only 3 ft. high ...	0·75		431
1,275	1,625	350	Revetment in fill, avg. 7½ ft	7·5		2,625
1,625	1,675	50	Cantle-Turner St. subway	12		600
1,675	1,925	250	Elevated railway on piers, 12 ft. ...	12		3,000
1,925	1,975	50	Chapman-Broome st. subway	12		600
1,975	2,200	225	Elevated railway on piers 10 ft. ...	10		2,250
2,200	2,700	500	Revetment in fill 6 ft. ...	6		3,000
2,700	3,350	650	Revetment in cut 3 ft. ...	3		1,950
3,350	3,750	400	Masonry parapet only 3 ft. ...	0·75		300
3,750	4,100	350	Revetment in fill 5ft. ...	5		1,750
4,100	4,500	400	Elevated railway on piers 12 ft. ...	12		4,800
4,500	4,600	100	Shirley-st. subway	12		1,200
4,600	5,050	450	Elevated railway on piers	12	Foot run.	5,400
5,050	5,150	100	Beaufort-st. tramway subway	12		1,200
5,150	5,400	250	Elevated railway average 15 ft.	15		3,750
5,400	5,870	470	Revetment in fill avg. 5 ft.	5		2,350
5,870	9,100	3,230	Perth station site, cut and fill ½ x 3,330 x 600 x 5—185,000 c. yds.	1/6	c. yd.	13,875
			For station building and sheds allow ...			20,000
			Land resumption in red, on ratable value			65,000
9,100	9,525	425	Revetment in cut to tunnel face, average height 10 ft.	10		4,250
9,525	10,300	775	Cap and cover tunnel under Charles-st. Leeder-st., 20 ft.	20		15,500
10,300	10,425	125	Revetment in cut average, 22½ ft. ...	22·5		28,125
10,425	10,525	100	Newcastle-st. tram subway	12		1,200
10,525	11,200	675	Revetment in fill, 7½ ft.	7·5		5,063
11,200	11,250	50	Charles-John-st. subway	12		600
11,250	11,600	350	Elevated railway	12		4,200
11,600	11,650	50	Charles-James-st. subway	12	Foot run.	600
11,650	11,950	300	Elevated railway	12		3,600
11,950	12,000	50	Charles-Roe-st. subway...	12		600
12,000	12,200	200	Elevated railway over West Perth suburban railway and Queensberry-st.	12		2,400
12,200	12,850	650	Elevated railway to Marquis.st. ...	12		1,800
12,850	12,950	100	Marquis-Wellington-st. subway ...	12		1,200
12,950	13,200	250	Revetment in cut height, 8 ft. ...	8		2,000
13,200	13,325	125	Revetment in fill to tunnel app., 8 ft....	8		1,000
13,325	13,375	50	Murray-George super-passage ...	12		600
13,375	13,600	255	Revetment in cut to tunnel face ...	18		4,050
13,600	16,250	2,650	The tunnel for double line	28		74,200
			The tunnel station, approaches, lift and and power, allow			47,000
16,250	18,125	1,875	The cliff gallery	30		56,250
18,125	18,825	700	The Narrows Bridge	70		49,000
Total length	18,825 ft.		total of formation.			£445,419

Add 3·56 miles of double line, 60 lb. rail, rails and fastenings, sleepers, plate-laying and ballast.

SCHEDULE B.

Abstract of Cost.

Chainage Length. Feet.	Particulars of Formation.	Average. Rate Unit.	Total. £
2,375	Revetment in cut, including parapet	17·9	42,475
2,470	Revetment in fill, do	6·4	15,788
975	Masonry parapets only	15/-	731
3,075	Elevated railway on piers	12	37,200
650	9 subways 50 to 100 ft.	12	7,800
50	1 super-passage, 50 ft.	12	600
775	Cap and cover tunnel	20	15,500
2,650	Tunnel	28	74,200
	Tunnel station, approaches, lift and power		47,000
1,875	The cliff gallery	30	56,250
700	The Narrows Bridge	70	49,000
3,230	Perth station site—forming	1/6 c. yd.	13,875
	Do. do.—land	4·3	65,000
	Do. do.—buildings, etc.	20	20,000
Total 18,825			£445,419

THE CORROSION OF IRON AND STEEL.*

(By E. A. Mann.)

The object of my remarks to-night is not to take a general survey of the whole of the large field which the title of my paper indicates. That would be too large a task, alike for my powers and your patience.

I wish rather more particularly to bring before you some of the results of the more recent researches in this important field and to show their bearing upon Engineering practice.

It is to be feared that in doing so I must, to some extent ask you to "lend me your ears" while I discourse as briefly as possible of certain chemical theories. I know that to many people a chemical theory is as much to be avoided as a new microbe, but while I will endeavor to cut it down as much as possible, a certain amount of theory is unavoidable.

There is a saying which always appeals to me—"Seek to know why, for this teaches you how and when"—and while as practical engineers you are engaged continually in finding the practical solution of problems which arise in your daily work, I feel sure that you also recognise that a theory will often serve as the master key which unlocks many doors of difficulty, when sometimes the secret of each separate lock cannot readily be found and that it is easier and wiser to carry with you one master-key rather than to have to carry a whole bunch at your girdle.

It is hardly necessary for me to remind you of the enormous economic importance of the corrosion of iron—yet a few figures may be pardoned. One writer gives the production of pig iron demanded by the world's requirements (See Illustration 1).

If we continue the curve as indicated by the broken line in the figure in 1920 the annual production of pig iron will be 100 million tons corresponding to a consumption of twice that weight of ore, and more important still, even if our stores of iron ore will stand this drain what about the consequent depletion of our coal supplies? If, as is the case, about 4 tons of coal or the equivalent thereof are used in extracting and preparing a single ton of steel from the ore this is the most important factor to be considered and it has been calculated that *if the consumption continues to increase at its present rate* all the coal seams that can be worked under existing conditions will be used up in 150 years.

One of the most important ways by which we can conserve our stores both of iron and steel lies undoubtedly in prolonging the life of those iron articles already in use, by either protecting them against corrosion or rendering the metal itself immune to the attacks of natural forces. The study of corrosion is evidently then one of prime importance.

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*For Diagrams, etc., see end of book

The chief result of this study in recent years has been the advancement of what is known as the Electrolytic Theory of Corrosion. The name, however, should not lead you to confound this theory with the explanation of the effects caused by the escape of high potential currents from mains, tramlines, etc., and to avoid such possible confusion it would be better perhaps to speak of the Electro-chemical Theory.

As the very name implies this theory is not a purely chemical one but belongs rather to that wonderful modern development of Physical Chemistry which almost amounts to a new science in itself and which has tended rapidly towards the breaking down of the previously existing dividing wall between the distinct sciences of chemistry and physics.

I must ask you then to follow me as patiently as you can for a short time into some of the purlieus of this science so that I may show you how some of the modern investigators have attempted to answer the great "Why?" which I have already indicated to you.

Dissociation Theory.

The theory of Electrolytic Dissociation states that when acids, bases, and salts are dissolved in water to form dilute solution they break down or dissociate into ions. Ions are atoms or groups of atoms carrying in relation to their masses enormous charges of static electricity (Illustrations 2, 3 and 4).

The positive hydrogen ion is the distinctive characteristic of all acids in solution, just as the negative hydroxyl ion (OH) is the characteristic of all bases in solution.

Water itself is dissociated to a small but perfectly definite extent into its ions Hydrogen (H) and Hydroxyl (OH).

Every metal when placed in water tends to dissolve in the water i.e. to assume the ionic condition, but it can only thus pass from the atomic to the ionic condition if it can obtain the necessary charge of static electricity. If the solution is acid (Illust. 4) there will be present hydrogen ions, which will give up their charge to the metal and so enable it to go into solution. The hydrogen gives up its charge and in so doing passes into the atomic condition and makes its escape from the solution as a *gas*.

If there is a rush of hydrogen gas this will keep the surface clear, but if the action takes place slowly the hydrogen ions tend to polarise around the electrode and form a hindrance to further action.

The important factor about the whole thing is the presence of free hydrogen ions which will enable the iron to be dissolved by giving up to it their static charge. There is thus engendered a flow of positive electricity from the metal to the solution.

Now it is quite obvious that if we could place in the solution a number of ions carrying a negative charge of electricity they would overpower and inhibit the action of the free Hydrogen ions by neutralising the positive charges they carry. Such negatively charged ions are to be found in Hydroxyl ions, and this I will recall to your mind a little later.

It must now be quite apparent that under circumstances such as I have just described to you the iron would be corroded. But I want to lay particular stress upon the fact that this is not the same as being *rusted.* Corrosion is the first stage ; rusting is the second, and much confusion will be avoided in reading technical books on the subject, if the distinction is always borne in mind.

If oxygen be present in the water the state of things depicted in the diagram will be only transitory. The iron in solution will at once be oxidised and deposited as *rust* which is simply a mixture of Hydrated oxides of iron afterwards in many cases further changed to carbonates. The hydrogen is the artillery which opens the engagement, the oxygen is the body of infantry supporting the attack.

I wish to impress upon you that the above is the simplest and most elementary case possible. In practice the question is complicated by many circumstances.

1. The water is not pure, but contains salts in solution which act as exciters and accelerators of the transfer of electricity.

2. The iron is not pure, but has associated with it impurities e.g. Manganese phosphorus etc. which may be electronegative to iron and in the presence of the existing agents described form local galvanic couples which multiply the points of attack. They are like an enfilading force which turns the flank of the defended position.

3. The physical condition of the iron is not uniform—varying degrees of stress in various parts of the metal can be clearly shown to give rise to portions which are relatively antagonistic in their state of electric stress, so that one portion will be electrically positive towards another—while after corrosion has proceeded for a time the polarity may be reversed.

All these considerations complicate and exaggerate the effect, but what I want to impress upon you is that they are all only particular instances of the one principle ; they all have their origin in the one basic theory of electro-chemical action.

So diverse a subject as the corrosion and preservation of iron could be encyclopedic if the attempt were made to take up every phase in detail. The protection of boiler tubes, of fencing wire, of ships' bottoms, or bridge

structures, of water mains may all present different problems from the practical point of view, and yet the same main principles can be applied to the consideration of each case.

Before going on to the practical application of these theories to the preservation of iron, I want however, first to say a few words about one very beautiful form of proof which has been devised by the American investigators.

FERROXYL.

Cushman and Walker have devised a mixture which they call Ferroxyl. This consists of a Gelatine which is impregnated with two solutions. One of these is changed to a pink color by the negatively charged *ions* such as Hydroxyl and the other develops a blue colour indicating the presence of positively charged ion.

I have some actual experiments with Ferroxyl here for your inspection which I would like you to examine when the lights are restored, but meanwhile I will first project on the screen one or two typical reproductions of the class of effect observed (Illustrations 5, 6, 7 and 8)

Having thus briefly discussed the causes of corrosion I feel that you will reasonably expect me to say something as to its prevention. I would like therefore to say a little on the question of preservation of iron.

As one of the principal writers on the subject has said, this question has three divisions.

1. The manufacture of a metal highly resistant to corrosion, e.g. Kutab Kinar—Delhi Column—50 ft. high, 16 inches diameter —a series of masses each weighing about 50 lbs. welded together 912 B.C. Free from rust, merely tarnished. Also old nails. (Illustrations 9 and 10).
2. The study of the passive condition which iron is capable of assuming, and maintaining the surface in an ennobled condition.
3. The general subject of protective coatings or treatment.

(1) It has already been pointed out that under practical conditions the corrosion which would be expected even in perfectly pure iron is greatly increased by the presence of impurities occurring in commercial samples of the metal. The galvanic couples thus formed act as accelerators of the trouble and spreading over the surface of the metal like sodent ulcers will soon destroy it— Manganese and other normal constituents of iron may have this effect. Even mill scale (magnetic oxide of iron) adhering to the surface of the metal is electro-negative to iron and unless forming a continuous coating, will greatly stimulate its corrosion.

Some attempts have recently been made therefore by preparing iron as chemically pure as possible to produce a metal which is incorrodible. Iron containing 99.95 per cent. of pure Fe, has been prepared and has been claimed to have largely solved the problem, but there is a great deal of contradictory evidence and this claim cannot yet be considered as proved. With all our modern scientific methods we have not been able to deliberately produce the qualities exhibited by some of the old hand-worked specimens of iron, the Delhi Column and many other specimens of ancient and eastern workmanship. It has been suggested that perhaps the very handworking of the metal removed from the surface, mill scale and other impurities, or produced a state of electrical tension in the surface of the metal which itself served as a protector, or again that the use of stone anvils (as in India) caused the iron to be covered with a thin protective coating of silicide.

We cannot say for certain—perhaps these old workmen had a secret which we cannot discover, but still more probably they " builded better than they knew," and the explanation is yet to find.

(2) *The Passive condition of Iron.*

If pure iron be plunged into nitric acid it is " ennobled " or rendered " passive " It is no longer capable of precipitating other metals from solution, and is to a great extent immune from corrosive attack, while its metallic appearance is not visibly affected. Many other solutions such as Chronic Acid, etc., are capable of producing the same effect. The reason for this is not certain—Several theories have been advanced but none are yet proven. That which is most in favor is that by this means an invisible protective layer of oxide is formed all over the surface of the metal. This, is however, hotly disputed and cannot yet be accepted as final.

The passivity of iron is however of great practical importance as the use of pigments containing the more insoluble Chromater, e.g. those of lead and zinc in paints applied to the surface of iron, promises to be a very valuable means of preservation, through the passivitv they produce in addition to the mechanical protection afforded by the pigment coating.

(3) *Protective Coatings and Treatment.*

The application of protective coatings to metal work is at once the most obvious, oldest and most widely spread method of artificial protection employed. You are better acquainted with these through your practical daily experience than I am, and it would be impertinence in me to dilate upon them. I only wish to refer, therefore, to one or two of the more important, in so far as they illustrate the electro-chemical theory which I have brought before you as the explanation of all corrosion.

Galvanising must easily take first place. It is probable that more than half the zinc produced in the world is used as a protective coating of metal on iron or steel. The virtue of course depends upon the fact that the zinc is strongly electro-positive to iron and therefore in any corrosive action which takes place the iron is saved at the expense of the zinc. Of course its protection cannot be perpetual as it suffers self destruction in its performance of its functions so that it is only a matter of time when, to make use of a common simile, the iron is reached over the dead body of its protector.

It must also be remembered that its effectiveness depends upon the evenness and continuity of the zinc coating without which its protection will sooner break down. Pinholes and inequalities in the coating will rapidly lead to the corrosion of the latter.

The same points require attention in connection with the protection of iron with tin—of such importance in the huge modern tin plate industry. Though here they are even more necessary since tin is not electro-positive to iron and the coating therefore requires to be more perfect. An important application of this in practical life is connected with the preservation of tinned foods.

I will show you presently a very delicate and interesting chemical method of showing how many imperfections can be disclosed in a piece of tin plate of apparently excellent quality.

Walker's Test.

One of the most interesting proposals for the technical production of incorrodible iron is that to cover the metal with a protective coating of Magnetic Oxide of iron. This is the basis of the Bower-Barf Wells, and other similar processes, superheated steam and air.

As I have already said the magnetic oxide (the same as Mill Scale) is electro-negative to iron—while therefore if the layer is made continuous (as can be done) it is very efficient, but if not it is a positive danger and acts as an accelerator of corrosion, so that this process is not applicable to iron which requires to be worked as the brittle coating of oxide then becomes broken exposing the iron to increased attack.

I need hardly, I think, refer at all to ordinary coatings of paint of the many kinds which are applicable to iron work. Their name is legion, their advertisers are energetic—their values are as various as their names. Each has some value, the life of each is limited, to be determined only by trial under particular circumstances.

The protection of iron from corrosion by means of electric currents must be scientifically sound, and is restricted only in its application by the circumstances of working.

If by means of the external application of an electric current a boiler, for instance can be converted into a negative pole, while an insulated rod of metal or other substance inserted into the boiler is made a positive pole —the boiler must be protected at the expense of the positive pole. This principle is, I believe, being successfully and increasingly applied.

As distinct from methods of treating the iron itself to protect it there is also the question of treating the vehicle by means of which its corrosion is brought about. This is of importance in connection with two great sources of trouble—boiler corrosion, and that of pipes conveying water.

This treatment of boiler water is so important that I could write a paper on that alone, but I do not intend to deal with this, more particularly to-night, but to pass on to what is really only another special application of the same principle, namely the protection and preservation of water mains.

Conclusion

As far as I am aware none of the numerous publications on the corrosion of iron refer to this matter at all, and as it is of special importance to us in this State, I will crave your permission to conclude my address to you to-night by a reference to this matter. What I say on this subject is also applicable to boilers.

I have already laid sufficient stress upon the important role played by water as a vehicle of those Hydrogen ions which are responsible for the primary attack upon the metal. I have also already suggested to you the possibility of counteracting the effect of these positively charged Hydrogen ions by introducing in to the solution an opposing force of negatively charged Hydroxyl ions. Such Hydroxyl ions are present in solutions of the Caustic Alkalis, alkaline earths, etc., of which group one of the most important and readily obtainable is lime.

I will now refer briefly to a few points connected with the very important experiment based on this principle which is now proceeding in our own State.

In 1903 the large Goldfields Water Supply 30 inch main, first supplied water to Kalgoorlie—in 1908 the evidences of corrosion leading to internal "tuberculation" were so serious as to lead the Chief Engineer, Mr. Reynoldson, to make a special report on the effect which this might be supposed to have on the scheme as a whole, and caused him to revise the original estimate of the duration of life of the main. He was led to the conclusion that in consequence of this the sinking fund would have to be materially increased. So important a matter was it that he estimated a further allotment of sinking fund would be required amounting to no less than £60,000 per annum, which could only be obviated if by some means the life of the main could be extended for five years beyond his revised estimate.

I need not deal in detail with all the steps taken arising out of this report. A full account of the whole matter was published as a departmental document in 1910, and is available for your perusal.

Suffice it to say that it was finally determined last year to commence treating the water on a large scale by adding to it quick lime at the No. 2 Pumping Station.

This treatment is based on the principle I have already explained to you since the lime on going into solution will provide a defending force of Hydroxyl ions according to the theory described.

In the mains supplying Perth from the Victoria Reservoir where also great trouble was experienced with internal corrosion, lime treatment has now been in force for 12 months and it is believed to be satisfactory though no definite reports are as yet available.

The effect upon the large Coolgardie Main cannot yet be properly judged, the period of operation has been too short and the arrangements for applying the treatment to the best advantage are not yet complete, but are awaiting the provision of a special large settling tank at No. 2 Station. This experiment which I believe I am correct in saying is the only one of its kind, and at any rate is certainly the largest in existence, will be watched and its result awaited with unusual interest.

It might be permitted me, however, to briefly refer to an experiment which was previously made to test this treatment on a practical scale, the result of which affords the strongest grounds for believing that the larger experiment will be successful.

The 6 inch Norseman pipe, 12 miles in length conveying the Mundaring water from Kalgoorlie to Kanowna, which was laid in 1904, in 1909 began to show serious signs of corrosion as indicated by perforations of the pipe from the interior. By treatment with lime this has been stopped. The history of this experiment can however be best shown you by the chronological table appended and by the curve given in illustration 11.

Ferro-Concrete.—On the above theory the steel in re-inforced concrete must be preserved by the lime in the cement used.

I fear there is nothing left for me to do but to apologise for the tax which I have put upon your patience.

I have felt somewhat like an aviator taking an aerial excursion over a wide spreading landscape. There have been so many advantageous spots on which to alight, which attracted by their special interest, that I have hardly known which to select lest having once lingered I might be tempted to stay too long, and so miss other localities of greater interest to you, if not to myself.

If, therefore, I have merely skimmed over certain regions of the field and appeared to treat them with scant attention, the difficulty of properly controlling my Pegasus must be my excuse, and I can only express the hope that the inducement may at least have been offered to you to make a personal excursion into those places which we have had to pass by to night so that you may more extensively explore their recesses.

KANOWNA MAIN CHRONOLOGICAL SUMMARY.

Year.	History.	Perforations
1904	August, Main laid	
1905-7	" "	
1908	October 27th Only 1 or 2 perforations to date....	2
	Rest of year, 7 per month	14
1909	To March 11th—7 per month	17
	From March 11th to June 15th—18 per month ...	52
	April and May—test peices inserted	
	May 20th—Lime treatment commenced, 25 grains. to gallon. Complaints as to hardness and taste Horses refused to drink the water..............	
	May 29th—Lime reduced to 18 grains	
	June 2nd—Lime reduced to 12½ grains	
	June 15th to 30th	2
	July, August, Sept.—July 29th to Sept. 28th (Main Scraped in sections)	6
	October	10
	November.................................	4
	December	2
1910	January, February, March—February—test pieces inspected	5
	March to October.—July 18th, lime discontinued..	0
	November. Water treated with lime at No. 2 P. S. near Mundaring; came through containing about 5 to 1 grain free lime to the gallon	1
	December	1
1911	January	2
	January to November	0
	July 13th. Test pieces examined	
	November 25th " " "	

See also diagramatic representation of the above in Illustration 11.

Discussion.

Mr. J. F. Ramsbotham said the subject caused more thought in England than in Western Australia, except perhaps for the Coolgardie pipe line. In England large railway companies and big dock companies spent an enormous amount of money, running into many millions every year, on the protection of iron in bridges, roofs and other structures. In Liverpool corrugated iron was worn out in twelve months. In Western Australia he had no doubt it lasted probably for twenty years without any effect at all. The reason to a great extent is the acids in the atmosphere. Week upon week in England there was nothing but dull days, practically very little sun and a good deal of wind and countless thousands of chimneys belching forth their smoke from chemical and other works, and that all told one long tale of corrosion. He remembered in Mr. Mann's paper he mentioned the protection of iron by lime mortar. They built a fairly large warehouse at Liverpool for tobacco, and it was built of cast iron columns, iron giders and joists, and brick arches and brick walls. Where the girders came on the walls you could see along the whole building (it was seven or eight stories) ; you could see in every storey a crack and a lift, which is to be seen now, and from examination it was found that corrosion had gone on in the iron and lifted the entire building. I was assistant at the time. We were building alongside another warehouse with thirty-six acres of floor, so it gives you an idea of the size of it, and in every case where the girders and joists came in the wall there was a pocket made and they were cemented in. It was most carefully done and there has been no lift in the slightest degree. Further than that, we protected the shell. We were most careful in getting the mill-bloom off the girders and joists. As soon as the mill-bloom came off they were immediately coated with cement wash, and if necessary when we were going to concrete them in, if there were any signs of decay, they were removed again and cement washed again before being concreted in. Then I saw another very interesting experiment being carried out, which took about two years to watch the result. A bar of polished steel was concreted in—in size 12″ x 12″ and 4 feet long—and thrown into the river. Two years afterwards it was taken out and the concrete broken, and the steel was as bright as the day it was put in. I did not do that personally. I can only say from what I have seen of it. I carried out some other experiments in connection with some ferro-concrete, in pulling out some steel rods in concrete after two or three months. In some cases we did not remove the mill-bloom and in other cases we did, and we got very considerably stronger adhesive force where the mill-bloom was removed, and I think in ferro-concrete work it ought to be a *sine qua non* that mill-bloom has to come off, and really the only way to get it off is the weather. There is not much rain out here, so probably it would mean washing it or something like that if you were anxious to hasten it. And that question of mill-bloom applies to painting, which

should not be done until the mill-bloom is removed. And then in connection with some steel gates that I was connected with they were the first steel gates they ever had in Liverpool, and at present the only ones. They were 141 feet from centre to centre and were very large, and the cost of protecting them was naturally very carefully gone into. On the outsides some patent paint was put on—very highly spoken of and supposed to be very efficient. I can only say that in a few months on the inside it came off, and within eighteen months the gates had to be taken out and taken into dock, scraped and painted again—not painted again, but tarred. Carefully cleaned and boiling thick gas tar was put on. We found from experience and consulting other people that that was really the best thing to do. The inside, however, which was more important than the outside to a great extent, because it would be difficult to treat afterwards if there is any decay—was coated with " Wells-Dove " (?)—(I think that is the patentee's name)—a sort of bitumen, and was carefully done in the first instance ; and I examined it myself, crawling through very small man-holes, from top to bottom, about eighteen months afterwards, and in countless places I knocked the bottom off and the iron underneath was absolutely perfect. You could not do that on your pipe line, but on a pair of gates you could do it. On a pipe line I should say it would be impossible on account of the expense.

MR. H. OLDHAM said Mr. Mann had referred in his paper, very confidently, to the result of embedding metal—steel or iron—in concrete, that as there was lime present there would be no corrosion There had been a good many experiments made and there had been perhaps one or two which might have shown that that was not always the case. He thought he was right, however, in saying that the consensus of opinion was that when metal is properly put into concrete it comes out bright whenever the concrete is broken. In any case, I may say that my experience as regards any ferro-concrete work which I have carried out and examined after has, in every case, led me to that conclusion. The Monier pipes, which were started here some six years ago, are very often cut for the purpose of junctioning, and in every case where we open them up we find the steel is quite bright, although, in the first instance, it may have been put in in a rusty condition. As regards the question of mill-bloom, I think that is a most important point. My experience goes to show that the best way to ensure good contact between the metal and the concrete is to put it in with a certain amount of rust on it. Of course, if the iron or metal is at all dirty or greasy there will not be good contact, but as far as my experience goes, within reasonable limits, the rustier the better. As regards the Victoria reservoir pipe line, which was referred to by Mr. Mann, there has not been an opportunity to examine the test pieces, but there is one important factor which has become very clearly evident as regards the effect of the lime in that case, and that is this : that every year prior to the use of lime on that main there was

considerable trouble experienced through discolouration of the water. There was a good deal of research in connection with it. It was considered first that the early water coming into the reservoir would come in discoloured, perhaps bringing some iron from portions of the catchment, which has a considerable amount of iron on the surface, and that perhaps this got into the pipes. It was found that the discoloration effect in the reservoir had become very well settled and there is no doubt now that the trouble is due to the fact that the water attacked the pipe *en route* and brought in a certain amount of iron rust. Since the lime treatment has been put into use there has been not the slightest sign of this discoloration. There is another point which seems to me pertinent to this matter. Rather recently the practice of putting a cement wash on the inside of pipes has come into general use. I have seen pipes, notably one of the large mains conveying water into Sydney, coated in this way. The original coating was tar—that is an asphalt mixture. This gave some trouble, and as there were two lines of pipes it was possible in winter to throw one out of commission to go through it, put steel brushes on to it, and cement wash the whole surface. Now, after cement wash, from figures that I have recently received, the pipe is in first-class order. That proves Mr. Mann's statement that as long as there is lime available there will not be rust. Nevertheless, some other experiments in this State have shown that the cement wash in some waters will not suit. That to my mind does not disprove the theory. It proves the fact that there is some active agent in the water which neutralises the lime very quickly. The cement wash of course is pretty thin and there is not a very great deal of lime available. I am confident, with Mr. Mann, that as long as there is lime available the corrosive action is prevented.

Mr. W. Leslie said it was true that the engineering profession owed a great deal to the chemist. They had enabled them now, with mixtures of iron, to produce regular rails. I think, though, that Mr. Mann refers to this new theory as the electrolytic theory of corrosion. I personally do not think it is quite a new theory, in so far that I knew it twenty or twenty-five years ago. It was referred to as galvanic action. But if I am wrong Mr. Mann will no doubt correct me. It was first noticed particularly in boilers and by experiment it was found that by zinc plates about the boiler the attack of the corrosion was transferred to the zinc plates; consequently, the steel boiler was saved at the expense of the zinc. I know also in another case of outside application some twenty-two or twenty-three years ago, when a steamer of the Castle line was launched. I think it was the first steamer that went out of the yard with manganese bronze plates on the propeller. And after the first voyage, when the ship came back, only being away about three months, and the ship was put into dock, it was found that there was a very great amount of corrosion going on in the stern post. Nothing of the kind had ever been found to take place with either steel or cast

iron plates, and at that time it was set down to galvanic action having been set up through the manganese bronze plates. The old method was the zinc plates. The stern post was treated in the same way as the boilers, that is, studs were inserted in the post and zinc plates were bolted on, and at least I know for twelve months (I had no opportunity of seeing after twelve months) these plates were regularly maintained and no further corrosion took place on the stern post. I would like, when Mr. Mann replies, if he would tell us whether he thinks the new theory is the old one under a new name. There is a good deal of it that is theoretical as yet, but I hope that the chemists will be able to go thoroughly into this matter and be able to tell us, as engineers, some absolutely positive way in which we can protect our structures after they are once erected. There is only one matter that I have marked off here that Mr. Ramsbotham refers to—I find that you started with 25 grains to the gallon of lime. I ask if there is any furring takes place in the pipe with such a large percentage of lime. I presume it would be possible that the lime might in a very short time very much reduce the carrying capacity of the pipe.

Mr. I. A. Ridgway said he should like to know, firstly, why the paint mark that was put on plates after rolling, generally, he thought, in white lead, remained on much longer than any other paint mark that is put on afterwards. Any plate that is left exposed to the weather will nearly always carry this shop-mark put on when the plate is hot long after the plate has lost its mill-bloom. Then, secondly, whether in a city there is any possibility of cast iron pipes or any other form of pipe being corroded by means of earth currents due, say, to electric tramways on the surface. He would imagine there is a possibility that one part of the pipe, if it is cast iron, might become a positive pole and the other portion might become a negative pole, and then presumably there would be some action set up, with the result that the positive pole would corrode away. And, thirdly, I should like to know whether burnishing has any effect in preventing corrosion. The author's reference to the Delhi column reminds me of another solution, I have heard of, on good authority, as to why the column has not corroded. What I heard was to the effect that the natives, in connection with some religious observances, had to swarm up to the top of the column as best they could, and the idea was that the natives, who were themselves covered with oil, kept the column well burnished. It seems quite a possible solution, even if rather a commonplace one.

Mr. G. E. Law said the author's remarks on the cause of corrosion of iron and steel were particularly interesting in that for some years past a good deal of his time has been taken up in fighting against attacks made on the outside of the 30″ steel main between Merredin and Kalgoorlie. On the outside of the pipes these onslaughts of rust are much more drastic in their action than is the case on the inside. The fact,

however, of the corrosion on the inside of the main being spread over a much greater area than on the outside causes one to take a more serious view of the former than the latter. On the outside of the pipes it is not so much "pittings" such as are found inside pipes and boilers—they might better be described as scabs or bites as it were out of the steel, and again in places it has the appearance of being eaten away by white ants As the perished coating is scraped from the plates the workman strikes. a yellowish looking lump and brings away a scab of rusted metal which is followed by water under pressure. In other places I have seen the locking bar with a gap about 1″ wide taken clean out almost to the plates, as though a bite had been taken out of it, and still free from rust close by; then again you may see a groove 3 or 4 feet long of varying width and depth, as though eaten away by a grub as in timber. A large number of these external penetrations occur in groups measuring perhaps 6 feet long by 2 feet wide, where the plate has a number of patches perhaps almost through. Lately an octagon steel bar has been found laying against the pipe after excavation having been there since the main was laid, *i.e.*, for the past ten years. The bar, which looks as though it had once been 1¼″ stuff, is now not more than ¾″ in diameter in most places. A caulking tool was also found under similar conditions. On this the rusting was most noticeable at the tempered end, where a piece was rusted right away. When a pipe is once exposed it is necessary to scrape and examine it at once, otherwise the action of the oxygen in the air loosens these scabs of rust and they break loose at most inconvenient times. Inside the pipe the pittings are fairly regular and uniform from end to end, the only one reason for their absence or the reverse is the quality and uniformity of the coating with which the surface of the steel is covered. These fittings are roofed over and protected by the casing or nodule of rust that completely covers each pitting and thereby protects the steel from further chemical action, as it has been noticed that when these small pittings arrive at a certain depth not more than ⅛″ they appear to stop, or if there is any further growth it is sideways. As far as the 30″ main is concerned, not one authentic case of penetration coming from inside has been brought under my notice, although I am continually on the look out for them. The case of the outside corrosion, however, is entirely different, the coating originally put on the pipes having lost its protective qualities almost from one end of the main to the other; The steel is right up against the course of the trouble all the time, *i.e.*, the moist clay and conglomerate which contains a strong solution of salts. Most of the bad patches are found on the bottom plate, where the pipes are in contact with unmade ground, yet again one occasionally comes across an isolated hole, the rest of the pipe being perfectly sound. There is evidence to show, however, that the hard carbon spots in the steel are especially very quickly acted upon by the gas arising from this electro-chemical action, the metal not being homogeneous as referred to by the

author. The life, of course, of a steel pipe buried in ground impregnated with salt is entirely dependent on its coating. If the coating in itself is not good or not well applied, or is allowed to perish, it favors the corrosion rather than prevents it, as it hangs like a blanket round the pipe and retains any moisture there may be in its vicinity. I have frequently picked off the 30″ main pieces of the perished coating, which is merely an ash, the particles of which are held together by flakes of rusted steel, which show that moisture has got in under the coating and set up rust. It is for this reason chiefly that I condemn hessian as a wrapping round pipes for, when the bituminous compound which is supposed to completely cover the bagging gets chipped off at any spot, the moisture impregnated with the salts of the surrounding soil creeps in and is held against the steel by the very means by which it is supposed to be protected and not only that, but it acts as a conveyor of moisture right along under the coating ; besides, the essential oil in the gas tar soon rots the hessian. Holes have broken through in pipes that have previously been exposed, scraped, tarred, hessianed and tarred twice again and the trenches refilled, after a lapse of three years. Although some few of the proprietary paints have proved themselves to be very durable on trials made with them on the 30″ main, yet for this main, as it stands at present, the coating that is being used will be hard to beat, viz., tar and bitumen put on hot on clean steel in fine dry weather. By several of these applications a coating ⅛″ thick may be obtained, and when it is found essential that the pipes must be buried again, as unfortunately is sometimes necessary, they must have several coats, but without the bagging. Mannesman compound has been found to be a very good substitute for bitumen, a good proportion being 5 lbs. of the latter to a gallon of tar. The following figures will give some idea of the results of external rust on the 30″ main and the work done to combat it between Merredin and Kalgoorlie, a distance of 210 miles. On the 30th June, 1909, 134 holes had penetrated the plates, the next year accounted for 155, the following year 105, and for the twelve months just ended 120, or a total of 514 penetrations to date. The worst ground has been dug away from 17½ miles of main, the pipes being left exposed and nearly two miles opened up and trenches refilled. These pipes have been thoroughly scraped, examined, and re-coated and repair bands placed over indentations nearly through as well as where the holes have occurred, the pipes being supported on jarrah blocks. In addition, almost all the joints in the bad ground have been exposed and left open. This work is still in progress and will be the means of saving considerably heavier expenditure at a later date.

Mr. W. A. Weller said, in explaining the corrosion of iron immersed in water Mr. Mann lays the whole blame on the free hydrogen ions contained therein. These hydrogen ions he explains attack the metal by giving up the electric charges associated with them, thus forcing a ferrous ion into solution loaded with the electric charge. Now it appears to me

that this state of affairs could not go on very long before the water was saturated with all the ferrous ions it is capable of holding in solution, and the amount of iron dissolved when a state of equilibrium is attained would be of no practical importance unless there were some substance present to remove the ferrous ions from solution and thus make room for a further consignment of them. The substances most effective in removing the ferrous ions are free acids, and if any such acid be present a ferrous salt will be formed and a new lot of hydrogen ions will be liberated to continue their corroding action. Under such circumstances corrosion will, of course, go on indefinitely as long as any free acid is present. Oxygen also is very efficient in disposing of ferrous ions and when it is present, as Mr. Mann has explained, rust is immediately produced, and, generally speaking, it remains on the spot forming by degrees the nodules with which most of us are familiar. I consider, therefore, that hydrogen ions by themselves would not do any great damage, but when aided and abetted by acid or oxygen the combination can destroy iron *ad lib.* This conclusion, if correct, is of extreme practical importance, as it opens up two methods of preventing corrosion of iron immersed in water: one by removal of the hydrogen ions, and the other by removal of free oxygen and acid from the water. The first method has been applied with success to the five-inch steel main between Kalgoorlie and Kanowna, as described in Mr. Mann's paper, but I consider the second method also is well worth bearing in mind. Regarding the chronological summary of the history of the Kanowna main, which was appended to Mr. Mann's paper, it may be of interest to members to know that two more perforations occurred in November, 1911, but from that date up to the end of June of this year no further holes have made their appearance. If the corrosion of this main had continued to increase at the rate obtaining prior to the commencement of lime treatment of the water conveyed through it, it is highly probable that the main would have become unserviceable long before now. The lime treatment saved its life. Since the discontinuance of the local lime treatment, however, the main is again corroding, but this corrosion is hardly noticeable for more than about two miles from the start of the main, and, as the absence of perforations indicates, is not as rapid as was formerly the case. Probably the fact that the water now carried contains a small amount of free lime, which is added at No. 2 Pumping Station, accounts for the diminution in its corrosive properties. The use of protective coatings for preserving iron and steel pipes from corrosion, lightly touched on by Mr. Mann, is a subject that I hope will provoke considerable discussion, as there is so much apparently contradictory evidence regarding their relative values. Speaking of the usual pipe dips of tar and pitch or tar and asphaltum, they appear to vary in durability with the composition of the water in contact with them. They afford excellent protection to the metal beneath while they are intact but with some waters the coating becomes perished and develops a porous

structure which allows the water to reach the metal and corrosion then takes place. Doubtless the composition of the coating is of great importance, but it is difficult to judge one without actual trial, and then it is too late to reject a defective one. Some criterion, both chemical and physical, is required by which the durability of a coating might be predicted. If this were available many of the troubles which fall to the lot of those engaged in the water supply business would vanish.

Mr. Mann, in reply, said Mr. Ramsbotham referred to the corrosion of galvanised iron and its varied period of life. I have no doubt that the atmospheric conditions in England are largely responsible for the cases he quoted, but we also find here a tremendous difference in the life of different kinds of galvanised iron. Cases have been quoted of galvanised tacks that have gone right through in less than twelve months, and it seems very difficult indeed to find any reason. But instances which I have known seem to throw some light upon it. I have had brought to me from water tanks samples of deposit removed from the internal ridges of the corrugations and when examined this was found to be pure hydrate of zinc. They are extreme cases of the galvanic action and the electrolytic action accelerated in these particular cases by the zinc coating being poor. By means of the Walker test the poverty of the zinc covering would be at once disclosed. With regard to the cement protection of girders, I was interested to hear what Mr. Ramsbotham said about that and also the influence of mill bloom. I would like to have known, in the cases where he took care to lay these girders in cement, if it was protective. I presume they were found to be protected by bedding in cement. That is a further confirmation that the alkaline nature of the bedding would serve as a protector. With the lime treatment a certain amount of furring up goes on in the pipes, but it need not be a serious difficulty. It can be minimised by having, first of all, your lime water well settled before you send it through the pipes. There is a good deal of furring going on in the Coolgardie main because they have not sufficient settling tank accommodation, and it is hoped to minimise that and send the water into the pipes in practically a clear condition. The amount of furring which goes on is chiefly dependent on the amount of air in the pipes. The carbonic acid gas in the dissolved air acts on the lime water and precipitates carbonate of lime on the interior of the pipe. There is also a certain amount of furring through the precipitation of hydrate of magnesia from the water by means of the lime. It is like a gelatinous sludge in the pipe and is very easily removed. Any furring which takes place will therefore only continue through the pipe so long as there is carbonic acid dissolved in the water which can precipitate the solution. At the Kanowna main it only occurred along a certain length of the pipe and beyond that the lime water ran without deposit at all. When a pipe was taken out and allowed to dry one could see just a faint white smudge over the surface of the iron. Its thickness could not be measured

MR. RAMSBOTHAM: Is the furring a protection?

MR. MANN: No, not in these cases where the carbonate of lime is formed by precipitation. It is very porous. In waters containing naturally a good deal of carbonate of lime you will get dense deposits of lime compounds on the pipe and there I think it is probably some protection. For instance, I think in a good many cases in England (and there have been some cases also on the Goldfields here), where waters containing a fair amount of lime naturally present, especially as sulphate of lime, have formed a deposit on pipes, which has, perhaps, been a protection. It is hard to say whether it is due to the deposit of lime or the naturally alkaline condition of the water.

MR. RAMSBOTHAM: Do the pipes get hot in the summer at all?

MR. MANN: Yes, in many places. I should say in the Goldfields they must get very hot, on the surface of a track of dark red soil when the pipe is small in diameter.

MR. RAMSBOTHAM: There would be danger of expansion if you have this furring.

MR. MANN: I think the furring is not so adhesive as to cause uneven expansion. Mr. Oldham referred to cases (experiments of ferro-concrete) which were not always successful, and I was glad to hear his experience in the matter. It is probable that some of those cases are like those quoted by Mr. Ramsbotham, where the mill scale had not been properly removed. I was also interested to hear about the Victoria Reservoir pipe main and naturally anxious to hear how the pipe is going on. I would like to ask him if he has got any evidence yet as to whether the lime is doing anything to maintain the full capacity of the pipe. Before the lime treatment was used it was found necessary to scrape the pipe about once every seven years and the tuberculation which was removed by the scraping was enormous. Of course, the scraping was necessitated by the diminution of the capacity of the pipe. I think that pipe has not been scraped for about three years now, and if so, and the lime is not proving of any benefit, there should be some evidence now of diminished capacity. I would like to know if Mr. Oldham can give us any evidence of increase or diminution of head due to lime treatment. We are watching the Coolgardie main for that.

MR. OLDHAM: The discoloration I referred to was undoubtedly due to ferric oxide in the pipe.

MR. MANN: Yes, exactly, it is due to the breaking up of the tubercles. I showed a photograph of the interior of the Victoria main before it was scraped. I think the capacity of the pipe was diminished, about 55%.

Mr. Oldham also referred to the value of cement wash on pipes in Sydney, but there is a good deal of evidence to show that the Sydney water is not nearly so corrosive as ours. Dr. Stokes, chemist for the water supply of Sydney, came over here on account of the lime treatment of the Coolgardie main to investigate on behalf of the Sydney Water Board, and has devoted a good deal of time to the subject. I have seen a copy of his report and, while he considers it is of value, he thinks that the corrosion in the Sydney waters is so much less than ours that it is not a matter that calls for treatment here. While he considers it is necessary here, it will not be necessary there, and its advantage would probably be outweighed by the immense disadvantage, which must not be lost sight of, which would be caused through adding lime to the water and increasing its hardness and so increasing the annual soap bill of the city. He figures out that something like £25,000 a year would be the extra soap bill of Sydney alone, caused by adding lime. Mr. Leslie has referred to the term " galvanic action," and asked if it is not the same as this electrolytic theory. It is in a way. Galvanic action, of course, derives its name from the original discoverer of the action—Galvani. The electrolytic theory to which I have referred shows it is not necessary always to have two metals in contact to cause this corrosion, and it is a very much larger question than merely galvanic action—the greater includes the less. The electrolytic theory will include galvanic action. There were many others intances of corrosion which could not be satisfactorily explained, and it is the study of these which has given rise to these particular chemical theories. Although I did not refer to other and older theories of corrosion (which are still held by some), especially the carbonic acid theory, I should have said that it was only recently that these older theories which were held were displaced by the newer electrolytic theory, and in its fulness the electrolytic theory has practically been developed within seven years. Protection must be adapted to the special case, and it is exactly the same principle as has been so well illustrated in another paper read to you to-night. Though you may have general theories, your special application must be governed by the circumstances. I am afraid that I cannot answer Mr. Ridgway's first question satisfactorily. Why the marks stay on is probably due to the fact that the metal is cleaner and the mill scale has been detached, or it may even be due to the great heat acting in some way upon the white lead itself and making it adhere—burning it on. With regard to the destruction caused by leakage from tram lines in a city, I have pointed out in the introduction of my paper that I was not dealing with this. Of course, undoubtedly, there is a tremendous amount of damage done in that connection in the mode stated by Mr. Ridgway. There is one more capable of dealing with this particular matter and that is Mr. Hancock, who has had a great deal of experience in it and who could deal with it much better than I could. There is a great deal of destruction caused in that way

and the main principles are just the same as in the particular cases which I have tried to explain in detail. I do not know about burnishing, but it is probable that the explanation of its effect is to be found in the answer to the question why does not " busy " iron rust ? It is generally supposed that the burnished condition of such iron (*e.g.*, railway tracks) prevents the lodgement of water, which is necessary to promote rusting. Burnishing would also be a protection in those cases where it removes the dangerous electro negative mill scale or other adhesions to the surface of the metal —it may have considerable effect in that way. But it is certain that a smooth surface does not rust like a rough one, owing, most probably, to water failing to find a lodgement. I was interested to hear Mr. Law's remarks, which were particularly interesting. Of course, all those cases which he quotes are typical instances of electrolytic attack, and he has, I think, well summarised why the attack is so much worse on the outside in some respects than on the inside. Those soils in which the pipe rest tend to form highly concentrated solutions comparatively with thewater which is inside. The solutions are highly concentrated and much more complex, and there is the danger of the presence of vegetable acids. All these will, no doubt, tend to increase corrosion in the way he mentions. And the peculiar worm-like attack would probably be caused by the following up of the impurities which are in the metal. Why the corrosion should proceed so much further from the outside than the inside is probably due to two causes—one of them, of course, the greater concentration of the solutions outside and also their being kept always in contact with the iron, because you must remember inside the water is flowing all the time and not in close contact with one particular point, but outside the clay keeps a poultice, as it were, alongside the iron all the time. It is possible that the corrosion outside may meet internal corrosion and so cause perforations in that way. I think Mr. Law said he very seldom found an external corrosion was met by an internal corrosion. The corrosion inside seems to proceed to a depth of about one-eighth of an inch and then spreads laterally. That is probably due to the altered polarity of the surface of the plate caused by rolling, etc., and different states of electrical tension in the surface of the metal as compared with the interior. When the corrosion reaches a certain depth the polarity is reversed. I quite agree with what Mr. Weller has said, except when he says that the ferrous ions would be removed by free acids. He is perfectly right about the oxygen serving to precipitate the iron after it has been taken into solution. It is the secondary action of the oxygen which forms the actual tubercles, and therefore I have distinguished between corroding and rusting. The corroding is the primary attack and the rust is the effect of the oxygen leading to the formation of tubercles. A committee of English experts considered this matter and reported on the Cologardie main, and the full report and discussion is contained in the official publication I have already referred to. They recommend de-aeration. It is simply a question as

to whether it would pay to do it, because it practically meant removing the oxygen from the water. It would mean keeping the whole of the water under a vacuum and it would have to pass through the receiving tanks and through the main without coming in contact with air. The experts at home proposed a special means of trying to do that which, I think, would be accompanied by great practical difficulties and those difficulties when reconsidered by the Departmental committee here led them to recommend that it should not be put into force until after the lime treatment by itself had been proved to be ineffectual. I am glad to know what Mr. Weller has said about the Kanowna main. I know there is a little corrosion going on now, but I pointed out that it is probably due to the fact that the Kanowna main is now only getting the residual alkalinity which reaches it from the Coolgardie main. It is only having from .5 to 1 grain. There is very little lime going into the Kanowna main at the present time and if that were increased the slight corrosion going on at the present time would probably be stopped. With regard to the life of protective coatings--that is a big question. In the tars which form the basis of many of these protective coatings are products of uncertain and irregular composition. We do not know quite what their composition is, they vary so much—one tar is not the same as another one. They are so varying that probably the diverse results which have been obtained are due to that cause, so that it is almost impossible to generalise. Different methods of preparing tar coatings have been tried; that is why I am afraid where you have compositions of such uncertain character as these it is impossible to lay down a definite line of treatment which can be employed in all cases, and I think that is a matter (as to which is the best kind of coating) which can only be settled by actual experiment. Even the best coating has been shown over and over again to have only a limited life. I think some American engineers have stated that even the best coating cannot be expected to last more than about seven years. So that in the case of a main—particularly where you cannot take it up and re-coat it—you will still have to consider the whole question of protective treatment after your coating is beginning to suffer from fatigue.

COASTAL EROSION: ITS ORIGIN AND PREVENTION.*

(BY I. A. RIDGWAY.)

The subject of coast protection is probably but seldom considered n a country of the size and population of Australia, where land is plentiful and cheap, except in those cases where some towns find it either essential or desirable to protect themselves against the inroads of the sea.

In smaller and older countries, however, the constant even if slow erosion of valuable agricultural land is more acutely felt and some form of coast protection becomes if not a necessity at least most advisable. In the case of land below the level of high water or spring tides protection is, of course, absolutely necessary.

The science of reclamation and protection of low-lying lands has been brought to a high state of perfection in Holland, but the principal conditions, viz., a low flat foreshore consisting entirely of sand, with which these works have to conform, are wholly different to those generally associated with sea-defence works in many countries and in particular Great Britain.†

Where towns are concerned economy need not be perhaps the controlling factor in the design of a sea-wall, for not only have the municipalities a large population on which taxes can be levied, but a sea-wall and the adjoining works can often be utilised so as to bring in a direct return, while in all cases an indirect return is secured since the value of the property fronting the sea-wall is enhanced.

In all other cases where sea defence works are required, whether they are to prevent the flooding of low-lying lands or the erosion of agricultural lands, it cannot be too often emphasised that the design must be an economical one, and more especially does this apply in the latter case, for here the whole cost of protection has generally to be borne by the landowner directly concerned, whereas in the former case a levy can be made on all those possessing property below a fixed datum.

The subject of coast protection is of itself so vast that it is impossible in this paper to do more than survey in a general manner the forces concerned and the effect of these forces on artificial structures.

Part I of this paper deals with those forces producing the phenomenon of littoral or longshore drift and erosion, while the effects and results of these forces on sea defence works are considered in Part II.

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* For diagrams see end of book.

† Royal Commission on Coast Erosion, in the United Kingdom. 3rd Report, Part III. par. 54.

PART I.

(A) Littoral Drift.

The simplest and the natural form of coast protection is the shingle or sandy beach collected and maintained by a continuous littoral drift, except in those cases where a state of equilibrium has been brought about by artificial or other causes.

Closely allied to, since depending on Nature's method of protecting the coast, is the method which utilises groynes, whereby the beach is heaped up locally, due to the groynes intercepting the supply of littoral drift as it travels along the coast line.

The importance necessarily attaching to littoral drift as a means whereby beaches are replenished, and its direct bearing upon the construction of sea-walls and groynes, make it essential that some mention of it should be made. Sir John Coode, in his paper on the Chesil Beach,* states that "the ultimate movement of shingle is always found to be in the same direction as, and never against, the heavier seas; and that it is frequently in opposition to the prevailing or strongest tidal current." In other words, the direction of the movement of shingle along any coast is similar to the direction of the prevailing wind along that coast.

The above statement, though not unanimously agreed to, even when first propounded, for the late Sir James N. Douglas† and others were opposed to it, has nevertheless found a very large number of adherents and the third and final report of the Royal Commission on Coast Erosion in the United Kingdom shows that still a large number of engineers favour this theory.‡

The other theory advocated at the present time by various authorities (*i.e.*, Messrs. W. H. Wheeler, W. T. Douglass, and Vaughan Cornish) states that the travel of drift is directly influenced by the current set up by the flood tide, and is therefore in the direction of the flood tide.

In the writer's opinion this latter theory is the more satisfying solution of the problem, though it must be understood that prevailing winds will materially increase the amount of drift, if in the same direction as the flood tide, and decrease it or even reverse it temporarily if against it, but that wind is not the true motive force is proved by the fact that littoral drift continues in comparatively calm weather.

Of the above two theories, the former is perfectly simple, needing no further explanation beyond saying that the prevailing winds are supposed to set up a longshore current and also to so influence the angle at which the waves strike the shore that shingle and sand are made to travel in the direction of the wind. The latter theory is more complex.

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* Proc. of the Inst. of C.E., Vol. 12, page 532.
† Royal Commission of Coast Erosion in the United Kingdom, Part I., par. 48.
‡ Proc. of the Inst. of C.E., Vol. XL., page 103.

The coast of Great Britain is eminently suitable for investigating the second theory, viz., that the current set up by the flood tide is the real transporting agent.

The portion of the great tidal wave generated in the Southern Ocean which travels up the Atlantic, divides on reaching the western entrance of the English Channel, the main portion continuing its journey along the West of Ireland, while the remainder again dividing flows up the English and St. George's Channels.

The main portion of the tidal wave which continues along the West Coast of Ireland, passes round the North of Scotland and creates the tidal wave which affects the whole of the East Coast and in due course meets the tidal wave coming up the English Channel just north of the Straits of Dover. This point constitutes a node. A similar node is formed at Morecambe Bay by a portion of the main tidal wave passing through the northern entrance of St. George's Channel and meeting the tidal wave coming up St. George's Channel from the south.

It will be realised from the foregoing that in general the heaviest seas and consequently the prevailing winds are in much the same direction as the flood tide There is, however, one important exception on the Cumberland coast, from Morecambe Bay to Workington. The flood tide here runs from north to south, while the prevailing winds are from the south-west.* In this case the littoral drift is in the direction of the flood tide, proving conclusively the superior influence of the flood tide on the movement of beach material.

It must be understood that local causes affect the general set of the flood tide and influence the travel of littoral drift in consequence.

That the travel of shingle along the coast, and probably to a large extent sand, takes place almost wholly between high and low water mark is certain, for if it were otherwise the known cases of beach denudation due to groynes, etc., extending from H.W.M. to near L.W.M. would not exist, for the beach material would have travelled past the groynes and then with the advent of offshore winds been deposited on the beach.

It has still to be shown why the travel should be in the direction of the flood tide any more than in the direction of the ebb.

There are two important reasons which give the flood predominance over the ebb.

The first, which is the most important, is given by Mr. Vaughan Cornish in his book on Waves of the Sea, where he states that " provided the tide runs freely the currents follow the same rule as the forward and backward currents of ordinary wind-waves of the sea, viz., when above

* Abernethy, G.A.

mean sea level they are forward, when below mean sea level they are backward," or, in other words, the current is in the direction in which the tide is making from half flood to half ebb. The change of level of the sea is deceitful and suggests that the current changes also, but this does not necessarily follow except in certain cases, *e.g.*, in a bay or river, where the water is more or less confined and therefore heaps up, this tendency being accentuated in a river by the addition of fresh water.

In such cases the current changes shortly after or as soon as H.W.M. is reached.

Professor Darwin in his article on Tides in the Encyclopedia Brittanica* bears out the above statement when mentioning the tides in the English Channel.

The obvious result, if the above statement be correct, is that the upper portion of the beach is subject to the flood tide and the lower portion to the ebb tide current. Now as the shingle, when present, is generally confined to the upper portion of the beach, and as this portion is subject to a heavier wave stroke, since as a rule it has a steeper slope than the lower portion, it is clear that it is more liable to erosion, and consequently the material thus eroded is carried along by the flood current.

The second reason as to why the flood current should predominate is due to a peculiarity of the flood tide noticed by Mr. W. H. Wheeler, who says that the flood tide comes along in wavelets of its own making which break on shore in an oblique direction.† Whether the flood makes in this way and if it does whether this manner of making assists longshore drift, the writer is at present unable to say, but he has often noticed that a sea seems rougher and the general run of the waves larger while the flood is making than when it is ebbing, as if a certain amount of momentum which was imparted to the waves during the flood was lost on the ebb setting in, thus causing a diminution of erosive power in the ebb. The actual transport of material along the shore does not take place along a straight line, but each particle of shingle, and to a large extent probably each particle of sand, moves in a zig-zag manner. The oncoming wave unnoticed by the eye possesses a certain longshore motion imparted to it by the tidal current. On breaking, the wave impels a pebble up the beach and imparts to the pebble some of its longshore motion, thus giving it a translatory movement as well as a movement directly up the beach. If the wave strikes the shore obliquely this movement is accentuated. As the water recedes again, carrying the pebble with it, it is probable that all translatory motion has been lost, and consequently the pebble travels down the beach without any longshore motion, only, however, to be carried up the beach again by the next wave.

* Encyclopaedia Brittanica, 9th edition.

† Minutes of Proceedings, Ins. C.E., Vol. CXXV., page 20.

It is practically certain that sand, except for the small proportion carried beyond L.W.M., is subject to the same motion, for sand can be collected by groynes and the foreshore raised in consequence in the same manner as shingle. Mr. Darley, in discussing Mr. Douglas's paper,* pointed out that he had seen groynes tried in New South Wales and that they had not been of the least benefit, but the author had replied that to the south of Lowestoft harbor 12 ft. of very fine sand had been collected in twelve months by a spur groyne, clearly showing that fine sand could be collected, and other cases might be quoted. Alluvial matter is, however, different, and one has only to see the extent to which alluvial mud from a large river, *e.g.*, the Nile, is carried into a tideless sea to realise that once such matter is in suspension it will remain so until either all current ceases or until the water becomes saturated. Consequently, alluvial matter eroded from the cliffs can never be counted upon to increase the quantity of littoral drift.

The above remarks on littoral drift have had especial reference to tidal seas, but in a modified form they apply to all those seas which though practically tideless yet possess a permanent longshore current. The coast of New South Wales is a case in point, for the flood tide current is replaced by a permanent ocean current and for a portion of the year by a monsoonal current.†

The direction of the ocean current is southerly and the prevailing winds being from the north-east tend to assist this current. The result is that sand travel along the coast has a southerly direction.

(B) Erosion and Accretion.

Without erosion there would be no littoral drift and consequently no accretion, and therefore erosion is of primary importance, not only because it is generally the chief agent of destruction to coast works, but because it is with the aid of littoral drift the salvation of many a foreshore. Erosion is an agent of destruction and also construction, and the economical design of sea walls depends on the use to which these forces are put. Erosion only and not the results of erosion concern this part of the paper.

It is clear from observations of a beach on a calm day and on a rough day that wave action is responsible for stirring up sand or shingle and then moving it up and down the beach. It is of interest to determine to what depth the erosive power of an ordinary wave is felt.

Some evidence as to wave action below the surface was furnished to the Royal Commission on Coast Erosion.‡ Sir William Mathews

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* Coast Erosion, W. T. Douglas, Mins. of Proc. of the I.C.E., Vol. CLXXXV.
† Bar Harbours of N.S.W., G. H. Halligan, Mins. of Proc. I.C.E., Vol. CLXXXIV.
‡ Royal Com. on Coast Erosion in the U.K. Part III., par. 13, III Report.

mentioned that sand and shingle are often found in the lobster creels in 120 ft. to 180 ft. of water off Land's End after a storm. A further case was the finding of sand after a storm on the gallery of the Bishop's Rock Lighthouse, off Scilly, at a height of 120 ft. above the water, the depth of the sea being 35 fathoms in the vicinity of the rock. This clearly shows that the sea bed must have been disturbed, for it was the only source from which sand could have come.

It is reassuring, however, when dealing with coast protection to realise that the height of a wave depends upon the depth of the sea at any particular spot, and since unbroken waves are oscillatory in character it is probable that the sea bottom is not materially affected until the shore shelves sufficiently to permit of breaking waves.

In this connection it has to be admitted that it is impossible to state definitely in what depth a wave will break, but very approximately it may be said that a wave will break on reaching water of less depth than its own height, measured from trough to crest. The wave breaks because the crest comes more freely, while the lower portion is retarded by the shore bottom, and the tendency to break is undoubtedly increased by a seaward undercurrent.

As soon as a wave breaks all oscillatory motion ceases and it becomes a wave of translation, which is impelled up the shore with an initial velocity dependent upon the height of the unbroken wave.

It is this latter wave which on its upward and downward path constitutes both the accreting and the eroding force.

This translatory wave formed on the collapse of the main onshore wave has its greatest velocity and therefore momentum at its start, and consequently it imparts a certain amount of its momentum to anything movable. It must also be remembered that any object which is carried forward by the upward wave is for the greater part of its journey water borne and further that since it impedes the upward flow it has for an instant an excess head of water on its sea side and consequently has a rolling tendency up the beach. This is more fully considered below. On reaching the limit of its upward run, the particles of water lose their velocity and gravity is free to act, and the water flows down the beach until it arrives at some point at which it meets the oncoming wave. This point depends upon the periodicity of the onshore waves. It is this downward flow which at its junction with the oncoming wave tends to create the undertow.

Fortunately for the beach, the downward flow starts with no initial velocity and consequently is unable to remove any stone which the upward wave may happen to have carried to its limit.

Any obstacle impeding the downward flow is subject not only to the kinetic energy of the water, but also to a potential head which is greater the greater the slope of the beach. Consequently, large stones are often easily moved, since the only resistance they offer to motion down the beach is sliding friction.

A further and important eroding agency is due to the water behind any obstacle obstructing the downward or in a lesser degree the upward flow, being at a lower level than the adjacent water on each side. The consequence is that water from on either side rushes in to fill the depression and in doing so creates a scour behind the obstruction which in time results in its removal.

If the above were the only conditions prevailing it is more than probable that the receding wave would allow of but little deposition on the beach, since apart from the initial momentum given to any beach material by a breaking wave, all the forces tend to the destruction of the beach. Mr. Vaughan Cornish, however, calls attention to one very important feature in the receding wave. This is the diminution of water contained in it on account of the large loss sustained by the percolation of water through the shingle or sand.

This effect is most apparent at the moment the wave starts to return, for after receding somewhat it receives again the water, but at a reduced velocity, which had percolated through the shingle.

It would seem that these percolation losses constitute the chief difference between the artificial forms of coast protection and the natural form, for whereas the best designed sea wall causes some additional erosion to take place, the beach naturally protected remains in practically a constant condition slightly lower after an onshore gale, but regaining its normal condition with the advent of offshore winds. The shape of a natural shingle beach varies somewhat according to circumstances, but the general curved shape has often been copied, with hardly satisfactory results, for the great advantage of a natural beach is its capacity for reducing the power of the receding wave, whereas the solid wall, with a smooth and hard surface, tends to augment its power.

The ideal wall must combine the stability of a solid structure with the wave reducing capacity of a natural beach.

PART II.

Having reviewed in a somewhat cursory manner the nature of the forces that produce coast erosion and consequently littoral drift, it becomes essential to know how best these forces may be combatted.

At the present time two distinct methods are in vogue, the one consisting in protecting the coast by some form of a sea wall, and the other in so raising the beach by means of groynes that the beach itself

protects the adjacent cliffs. In practice these two methods are often used in conjunction with one another, the groyne being supplementary to the wall. For the reason that the sea can pass round the head of a groyne unless it abuts against a hard rock cliff, it is seldom that one finds groynes independent of a sea wall. On the other hand, sea walls are frequently constructed without adjacent groynes. The greater diversity of shape the greater cost, and the more general use of sea walls over groynes, has led the present writer to confine this portion of the paper to the satisfactory design of sea walls, the more so as groynes, though built of various materials and in different ways, have when complete of necessity much the same profile.

A proper and economical design of a sea wall requires that the forces tending to wreck the wall be thoroughly understood.

The forces may be conveniently summarised as follows :—

(1) Erosion of the foreshore at the foot of the sea wall, causing the wall to either overturn or slide bodily forward ;

(2) General beach denudation, resulting in an exposure of the base of the wall and consequent probable overturning or sliding ;

(3) The creation of a hydrostatic head at the back of a sea wall resulting in overturning or sliding ;

(4) Direct wave action, causing local or general fracture and consequent failure of the wall.

(1) Erosion of the Foreshore at the foot of a Sea Wall.

The first of the above causes of possible failure is undoubtedly the most serious.

The erosive action of the sea is continuous and all sea walls should be designed to minimise this danger.

The first objective in all sea walls must be a good foundation. In very many cases, however, this aim cannot be achieved, for a sea wall has to be built where it is needed and the wall must suit the foundation and not *vice-versa*. On those beaches, however, where rock or good clay lies at a reasonable distance from the surface the wall either in part or whole section should be carried down to the firm foundation. The initial expense may be great, but where a wall is exposed it is false economy to neglect the advantages of a good foundation, even if some distance below beach level.

An important point to settle seems to the writer to be the level of the base of the wall with reference to beach level. On most beaches two distinct slopes are visible, the slope on what may be termed the upper

beach being greater than the slope on the lower portion of the beach, the junction of these slopes being between high and low water mark.

In many beaches free from sea defence works the upper slopes form a natural protection to the coast. But in the case of a coast where the sea can wash freely against hard cliffs this upper slope is often non-existent, despite the presence of a sandy foreshore, for the reason that the recoil of the waves from the cliffs prevents the accumulation of drift. The conclusion to be drawn from this seems to be that a sea wall should always be founded at a level below the line of the lower slope when produced shorewards, or, in other words, an estimate must be made as to the probable final beach level at the toe of the wall and the foundations designed accordingly.

A case in point is the wall shown in Fig. 2 (Wallasey Embankment new wall). Here it was considered probable that the final beach level would be as shown on the diagram, but, despite this, the vertical portion of the wall was carried down to the hard boulder clay.

In the case of a wall described by Mr. W. T. Douglas in his paper on coast erosion before the Institute of Civil Engineers,* erosion, viz., at the rate of 10 ft. per annum was so vigorous that two heavy concrete walls were successively overturned, due to the insufficient depth of foundations. It was also mentioned that the section of the foreshore, previous to a wall being built and after both failures, remained exactly the same.

It must not be thought that erosion will cease and that a wall will become immune from possible failure simply because it is founded well below the general level of the beach, for experience shows that this is not always the case, but it does make it possible to arrest erosion more easily either by the timely introduction of groynes or by adding an apron to the wall.

In this respect the sea wall below the Albert Drive, at Scarborough, England, shown in Fig. 3, is of interest.

Mr. Smith, the Borough Engineer of Scarborough, in his evidence before the Royal Commission,† stated that the shale in front of the wall had been eroded to such an extent that it became essential to extend the apron, and later to construct some groynes, which have proved to be very effective.

Circumstances, of course, determine the use and possibilities of groynes, and whether they can be suitably used as an adjunct to a sea-wall.

As an adjunct to a sea wall the above case proves their use, but in many cases they are neither suitable nor even possible.

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*Mins. of the Proc. of the Inst. of C.E., Vol. CLXXXV, page 98.
†Royal Commission on Coast Erosion in the U.K. III. Report, Part 3, par 22.

In the case of the wall shown in Fig. 2, the foreshore for some distance from the wall consists of a layer of peat some three or four feet thick. This peat directly overlies a bluish clay, which is not only very easily scoured away, but is of such a nature that if a layer of it is exposed it will become during a storm almost a fluid. Along this shore it is certain that in time the peat bed (which is the remains of an old forest) will be washed away and the blue clay become exposed. It is clear, therefore, on the grounds of expense alone, that groynes, despite there being a certain amount of littoral drift are not suitable for this shore.

Experience seems to show that where the blue clay is exposed the general foreshore will not fall below a certain level, but rather that failure to a wall would arise out of the liquefying of the clay by wave action, resulting in the sliding forward and collapse of the wall.

The reality of this danger was well illustrated in the case of a curved wall which is adjacent to but not part of the wall shown in Fig. 2, and which happens to be on the same formation. When built the peat bed referred to above also extended along the whole length of this curved wall and it was part of the design that the toe of the wall should be extended as the erosion of the peat proceeded. This, however, was not done, and as a consequence the waves during some stormy weather so liquefied the clay that a large portion of the wall collapsed and slid bodily forward.

The wave action on the ground at the toe of the wall was undoubtedly accentuated by the shape of the wall, causing a recoiling mass of water to strike an oncoming wave at this point. In the original design of this wall some wave-breakers or "dentals" were shown on the curved face, but these were, unfortunately, omitted in the construction. A further circumstance possibly contributing to the failure of this wall is mentioned below under heading (3). The methods adopted in the above case to prevent a further disaster of the same kind occurring again were, of course, if not decided by at least largely influenced by the financial factor and consequently may appear to be somewhat of a temporary nature. Opposite only that portion of the wall which collapsed a heavy mass concrete toe was placed, but elsewhere along the wall where the blue clay was exposed the foreshore was first consolidated by tipping on it a large quantity of stone and then rough pitched for a considerable distance from the wall, the intention being, of course, to prevent direct wave action on the clay. As far as the writer knows these measures have been successful and the more so as the pitching is gathering a certain amount of sand and shingle which help to maintain the stability of the beach.

The case of this wall and the Scarborough sea wall show very clearly that a wall with a curved profile by itself does not arrest erosion at its base, but would on the contrary appear to accentuate it.

To overcome this erosion various devices and designs of sea walls have been tried. The projections or dentals on the sea wall in Fig. 2 seem to be successful, but the level of the foreshore prevents as yet their full capabilities being realised, but that the recoiling wave is broken up by them there is no doubt.

This wall (shown in Fig. 2), belonging to the Wallasey Embankment Commissioners, was constructed in two portions, the earlier portion colored neutral tint was designed by the late Mr. G. F. Lyster, and was built about the year 1895. The foreshore at that time was some 4 ft. above its present level and when first constructed it was realised that the wall would have to be extended at a later date. The extension was designed for the Commissioners by Mr. A. G. Lyster, Engineer-in-Chief of the Mersey Docks and Harbor Board, the writer being Resident Engineer. The extension has not as yet been carried out for the whole length of the earlier wall, but will be added as occasion demands.

The wall is of an interesting and somewhat unique type and is economical both in construction and maintenance.

The main feature of interest lies in the platform or "verm" placed just above H.W.M., on which is spent all the energy of a breaking wave, and this successfully prevents the receding water acquiring any great velocity such as is acquired by a recoiling wave on a curved wall. The concrete projections on the surface, conveniently known as "dentals" are also of interest, and, as already mentioned are designed with a view to reducing the flow of the upward wave and the force of the subsequent recoil.

As pointed out above, the extension was designed with a view to the probable final level of the foreshore. In every case the vertical portion was carried down to the solid boulder clay, thus, apart from general stability, effectually preventing a run of sand or alluvial matter from under the wall, causing local or general failure. Vertical walls or walls with only a slight batter do not seem to be quite as liable to erosion as a curved wall, but if not so pronounced it undoubtedly goes on.

In the case of the sea walls at Blackpool (Lancashire) the Corporation Engineer, Mr. Brodie, who designed and constructed the two walls, mentioned in this paper, told the writer that a certain amount of erosion was experienced with practically vertical walls and had to be combated. Fig. 4 shows a wall with only a slight batter recently constructed at Blackpool and piling is placed as a precaution in front of the wall. The wall is of somewhat extra thickness for the reason that it is intended to utilise the space between a cliff and the back of the wall as a Corporation tip, and consequently no support can be derived frcm the back filling for some years.

A vertical wall has many advantages, including compactness, ease of construction, and its adaptability for the use of groynes, yet it is sometimes discountenanced on account of the violent wave action against it during an onshore gale, and the consequent drenching of any parade which may be at the back of the wall. This latter effect is lessened by introducing a bull-nose, as in Fig. 4.

The fact that at the foot of a vertical wall there must be a considerable undertow as well as a heavy pounding action on the foreshore, points to the necessity for making the foundations of a vertical wall exceptionally good.

Fig. 5 shows a section of a wall designed by Mr. W. T. Douglas for Hornsea, on the Yorkshire coast, to be used in conjunction with groynes. The wall protects cliffs of glacial formation, which, previous to the construction of this wall, were subject to very severe erosion.

There is still one other type of wall, if such it can be called, which, being based to some extent on Nature's method of protection, is eminently suitable for lessening the quantity of erosion. The type referred to is the pitched slope or embankment which is being largely developed today by the aid of ferro-concrete. A pitched slope acts in the same way as a steep natural beach in that it allows free expansion for breaking waves, thus reducing the force of the recoiling wave. The main difference lies in the fact that percolation can take place in the one while it cannot in the other; but a rough surface as is presented by a pitched slope considerably retards the receding wave and makes the embankment more efficient.

Fig. 1 shows a cross section of the so-called Old Wallasey Embankment, which with the new work already described extends for some 4,400 yards long the Wissal Peninsula. The Royal Commission describes the Wallasey Embankment, *i.e.*, old and new work combined, as one of the greatest sea-defence works in the country.* The Embankment is certainly an excellent example of this form of construction and the stability of the sandy foreshore proves its effectiveness.

From an initial cost point of view a pitched slope is, if circumstances are suitable, economical, but maintenance cost is apt to be considerable, for pitching is easily damaged by floating wreckage, and the possibility when once the skin is broken of further pitching being undermined and washed out must be guarded against, either by laying the pitching on clay or by adopting some other means.

This pitched slope or embankment type of defence-work has been considerably developed in Holland largely by M. de Muralt, who has introduced ferro-concrete work.

*Royal Commission on Coast Erosion in the U.K. Report III., Part 2, par. 105.

Figs. 6 and 7 show two typical sections of sea-defence work built on the De Muralt system. Fig. 7 is designed to be specially suitable in moderately exposed positions, while both seem to be eminently suitable for the protection of sandy coasts such as exist in Holland.

For further information on this particular form of protection and others in vogue in Holland one would do well to refer to Mr. A. E. Carey's paper on "Winning of Coastal Lands in Holland."*

Under certain conditions and in those places where the absorption of land by defence works is of no consequence, where a good backing may be obtained and where no excessive excavation is required, for the foundations, the De Muralt reinforced system or any other form of pitched slope protection work seems to be specially suitable, being generally of low first cost and, if in sheltered situations, of small maintenance cost.

Apart from these advantages, the erosion at the foot of the slope is usually small, for the slope is of necessity not greater than the angle of repose of the ground, while the stepped surface in the De Muralt system or the rough surface when the pitching is used, further safeguards the shore.

Large rubble is occasionally utilised for protecting a shore and, if circumstances and conditions permit of its use, there can be no doubt as to its efficiency. The protection of the coast at Fremantle is effected by this means.

Where it is desirable to economise space a pitched slope and a vertical wall may be used in conjunction. Fig. 8 is a typical section of a wall recently built at Blackpool where it is subject to a heavy sea. The slope, which is about 2 horizontal to 1 vertical, is pitched with basalt set upon a mattress of concrete, and is protected at its foot by a line of sheet piling held in position by a longitudinal walling bolted to a series of king piles.

No mention has yet been made as to the effect of oblique wave action on walls and the consequent probability of extra erosion.

There is no doubt that given favorable circumstances oblique wave action can increase the erosion at the toe of a wall by creating a longshore current along the foot.

Long slopes are naturally not so much affected by this action, but a well designed wall should be proof against any excessive trouble from this source.

It must be repeated that where possible groynes should be experimented with, and, if successful, they ought to be used in conjunction with the wall, for they are agressive and constructive, and may enable a lighter section of wall to be used.

*Minutes of the Proc. of the Institute of C.E., Vol. CLXXXIV.

(2) General Beach Denudation.

General denudation of any magnitude is generally caused by some obstruction either above or below the place affected, according to the direction of the flood tide preventing the flow of longshore drift. Any wall is liable to be denuded at its foot from this cause, and the only satisfactory remedy is to remove, where possible, the obstruction, and so restore the former conditions.

Apart from natural obstructions, breakwaters, jetties, piers are all liable to cut off the supply of littoral drift and thus cause denudation in their vicinity, but probably the most usual cause is the introduction of some groyne, which if built to its full height when first constructed is quite capable of cutting off the whole supply. To prevent this possibility groynes are now often built in stages, additional height being added to the groynes as the beach is raised. By this means no large quantity of drift is ever held up at one time, with the result that there is no denudation.

Information as to the best arrangement of groynes may be obtained from many sources, but, generally speaking, groynes extending from the wall to L.W.S.T., are placed at right angles to the shore, and spaced at a distance about equal to their length. In those places where longshore drift exists, the possibility that the quantity of drift available might be reduced or even cease altogether, due to the better protection of adjoining coastal lands (the source from whence it comes) must not be overlooked, and points to the fact that a deep founded sea wall is an advantage.

A further cause of local denudation, more especially on open sandy beaches and estuaries, is the somewhat erratic movement of low water channels. Suitable groynes or, if the channel is worthy of the expense, some form of stone revetment may with advantage be used to confine the channel to a safe course.

It need scarcely be added that all forms of artificial removal of beach material, for other purposes than coast protection in the particular locality cannot be too strongly deprecated. Certainly on an extensive foreshore the removal of material seems to be but a trifling matter, but experience proves that the little beginning is no guarantee as to what the end will be.

(3) Hydrostatic Pressure behind Sea Walls.

All walls from the nature of things are designed to stand the pressure exerted against them at high water, and the fact that they are almost invariably filled in behind disposes of any possibility of failure from this cause. The hydrostatic pressure which can be exerted at the back of a sea wall is, however, a very serious matter and would appear to be often overlooked, whereas too much attention cannot be paid to this matter.

Naturally, the danger is more apparent in cases where the tide recedes from the wall at L.W. for the counteracting pressure against the face of the wall disappears.

Where towns are concerned, there is generally an efficient drainage system to carry off all storm water before it has time to percolate into the filling at the back of the wall, and, further, the usual promenade adjoining the wall ought to be made waterproof and given sufficient slope, to allow of any water which reaches it from breaking waves returning to the sea.

In cases such as these the only danger to be anticipated results from the breaking of the watertight covering of the promenade during a storm and the consequent rapid saturation of the filling at the back of the wall. Provision must, therefore, be made against this possibility by giving the promenade if in an exposed position sufficient strength and by providing suitable weep holes in the wall itself.

This possible cause of failure is more likely to be realised in those districts where walls are constructed purely for coast protection purposes.

In such cases, where walls are often backed by sand hills or some other porous soil, care is required, for not only does the sand afford a catchment area for all the rain, but it will readily absorb all the water which during an onshore storm is driven over the wall. The result is that if the confined water cannot get away sufficiently rapidly the wall will on the approach of low water be subject to a dangerous outward thrust. To avoid the possibility of this danger the land adjacent to the wall must be protected and in addition sufficient weep holes provided in the wall for the discharge of rain and wave water.

The above factors must necessarily influence the design of any wall required for work under such conditions, and one cannot fail to realise that in these circumstances the embankment type of wall (Figs. 1, 6 and 7) and the berm wall (Fig. 2) are eminently the most suitable for the needful protection is secured not by an addition but by the economic utilisation of the wall itself.

The failure of the curved wall mentioned previously in this paper may have been in some measure due to the hydrostatic pressure exerted at the back of the wall, for beyond the asphalte promenade which adjoined the wall the sand was uncovered and liable to become saturated during a severe storm. It is, of course, impossible to say to what extent if any failure was due to this cause, but the condition of the foreshore after the disaster leads the writer to think that back pressure was at least partially responsible. With reference to detailed design, it may perhaps be mentioned that parapet walls, though useful as a protection, should where possible be dispensed with in favour of a railing, for they are not economical and do not add materially to the efficiency of the wall.

(4) WAVE IMPACT AND LOCAL OR GENERAL FAILURE.

Failure from this cause may be more general than is supposed, more especially in those sea walls or embankments which are pitched and thus expose seams and joints to the action of the sea.

If a mass of water having velocity v is suddenly stopped by a sea wall, then the pressure on the face of the wall becomes almost instantaneously equal to approximately $\frac{V^2}{2G}$ feet of water.

Confirmation of this is afforded by the results obtained by Thomas Stevenson, who carried out a series of experiments with a specially constructed dynamometer, on which he recorded maximum values of 3 and 3½ tons per square foot.

With a possible face pressure of this magnitude it is not surprising that walls are often damaged and blocks started from their joints, the motion of the blocks being invariably opposite to the direction of impact.

This phenomenon is explained by such authorities as the late Mr. Vernon Harcourt and others as being the result of either an air or water pressure, caused by a wave striking the face of the wall and compressing the air, if air be in the joint, or, if water, subjecting it to pressure. In either case the result depends upon the size and extent of the crevice, but it is easy to realise that if the joint be left it is only a matter of time until the outward thrust due to compression is sufficient to start the block.

Though undoubtedly great pressure can be exerted in this manner, yet if it is what it is generally supposed to be, viz., a direct reproduction of the wave pressure on the face, it would hardly seem sufficient to produce the results which are known to have been produced as a consequence of a heavy sea.

In this connection a paper on "Wave Impact on Engineering Structures,"* by Professor A. H. Gibson, is especially worthy of notice. In experiments carried out by him he has proved, and it would seem conclusively, that air pressure in the joints of a wall has a greater effect than is generally realised, and, further, that under certain conditions a water hammer action may be set up. One cannot do better than quote *verbatim* from Professor Gibson's paper. He says:—"The main conclusions to be drawn from the investigation are that while on the assumption of simple hydrostatic transmission of pressure the effective internal pressure due to wave impact cannot exceed that exerted by wave impact on the sea face of a breakwater, the pressures produced, if the energy of the wave is devoted to compression of air in the open joints, may amount to approximately twice this magnitude. If, however, conditions are favourable to the production of water hammer, considerably greater internal pressure, up to some fifteen times the face pressure, with very high velocities of impact, are to be regarded as possible.

*Minutes of Proc. of Inst. of C.E., Vol. CXXXVII.

"The results suggest the desirability of providing a free outlet for such water as may percolate to the interior of a sea wall or breakwater, by means of a series of weep holes or drains opening on its sheltered face. Such drains, preventing the accumulation of internal water, would be an effective guard against the production of internal pressures of sufficient magnitude to affect the stability of the structure, whether due to water hammer or air compression."

The above shows very clearly to what serious forces walls are exposed, and points to the fact that mass walls are preferable to masonry walls, and would appear to show that the practice of facing concrete walls when subject to heavy seas with ashlar work or concrete blocks is apt to be detrimental. Apart from the question of increased pressures due to air compression or water hammer, the direct wave force on a pitched slope is often serious and it is wiser and safer to limit, where possible, the use of the pitched slope, unless specially well supported and backed, to those situations where the waves strike the shore obliquely and are of small magnitude. These cases are, of course, comparatively few, for oblique waves in the offing tend to become parallel with the shore on account of the shelving beach. Experience shows that a very light pitching will suffice if the waves invariably run with their crests at approximately right angles to the pitched slope.

The point emphasised by Professor Gibson in his paper, that open joints may cause serious troubles unless properly drained, shows that if masonry work is used it should be very carefully attended to and the joints kept well pointed, and further that in mass work cracks should be prevented as much as possible by introducing at certain intervals some form (*e.g.*, asphalte) of expansion joint.

On the face of some walls projections are introduced, occasionally after the style shown in Fig. 2; but more generally the projection takes the form of a bull-nose (Fig. 4) or overhanging portion designed to throw the wave away from the wall. When such projections are contemplated care must be exercised in their design, so that the lifting tendency exerted by a wave is reduced to a minimum, otherwise a wall, unless of a very massive design, is apt to be shaken, and the effects though not apparent at first may eventually bring about the destruction of the wall.

Conclusion.

The intention in the foregoing has been to give in a general manner some indication of the forces which have to be successfully opposed and therefore of the essentials required in satisfactory and economical sea wall design.

Consequently, the writer has not attempted to deal in detail with any particular design, for it is essential that it should be realised that the design must be adapted to the locality, and that it is impossible to

fix upon a certain design as the most economical under all circumstances. It is, however, legitimate to suppose that there is some design which, other conditions being equal, would be more suitable, more adaptable and more stable under wave action than any other. The question at issue, therefore, is the most suitable profile for a wall.

In this connection the writer had the opportunity some time ago of obtaining some sections of a clay bank subject to a fairly heavy wave stroke. The waves broke approximately parallel with the bank, the latter being roughly pitched with large loose burrs, which were quite free to settle. The two sections (Fig. 9) of this bank are interesting in that they give some indication of the shape a plastic surface will take up when subjected to wave action. These sections clearly show that there is a tendency to form a platform or berm, a result also often noticeable in rubble work subject to heavy seas and equivalent to the terracing of natural beaches. These sections would seem to give additional proof that the wall shown in Fig. 2 is eminently suitable for coast defence in that it follows the profile which offers the least resistance to wave action and is at the same time most stable under its influence.

The length of the berm necessary for efficiency can only be decided by experience and consideration of the conditions, economical and geological. It should, however, be always of sufficient width to allow of the wave expending itself. The merits of the curved wall have already been considered and its similarity to the " full " of a natural beach is one of form only. Probably the most that can be said in favor of the usual type of curved wall over the vertical wall is that the former is generally better able to throw a wave clear of itself and thus better protect the adjacent land or parade, though this advantage is neutralised by the introduction of a bull-nose or overhang on a vertical wall.

Curved or vertical walls, unless used in conjunction with groynes for true coast defence work cannot be recommended on account of the probable high maintenance cost, for obviously the most suitable sections are those which reduce maintenance to a minimum even at a slightly increased first cost.

To minimise erosion the adoption of some form of wave breaker or dental is an assistance. The method of stepping the surface of slopes might perhaps with advantage be more generally applied to sea walls, the more so as stepping in no way subjects the wall to a lifting force.

The sufficient and effective drainage of the adjoining land and the consequent weep-holes in the wall must not be omitted from the design of any work, and should have an important bearing on the section adopted. while the geological composition of the country must of necessity be an important factor in deciding the type.

Groynes have not figured in this paper to the extent that their use entitles them, for the writer has been acting on the principle that the groyne is rather in the nature of an adjunct to a more important work, and may advisedly be constructed when circumstances demand. It must not be forgotten, however, that there are cases where groynes may be of real service without the aid of any sea wall.

This paper would hardly be complete unless mention (slight though it be) were made of the erosive power of that other agent—the weather, which, unknown and unseen by the majority, demolishes cliffs whether of hard rock or sand, time alone being the controlling factor. In many cases a little money expended in time on preventive works might accomplish much, whereas later the expense might be prohibitive. Chalk, limestone and all cliffs of similar nature should be treated in time and made better able to withstand the weather erosion. Of the various measures tending to allay this erosion the following are the most important :—

(1) Sloping the cliff to its angle of repose, and if the height warrants it the insertion of terraces ;

(2) Efficient and suitable drainage ;

(3) Planting shrubs, bushes, etc., where possible over the cliffs ;

In the case of sandy localities planting is often carried on with advantage, and among many plants suitable for binding the sand and protecting the dunes one may mention marrum, lyme grass, and some species of spinifex.

It is realised that this paper can but touch upon the subject of coastal erosion ; nevertheless, it may be stated with absolute certainty that whatever the problem involved, whatever the situation, success can only be economically and permanently obtained if the policy be changed from one of defence to one of offence.

Discussion.

Mr. J. F. Ramsbotham said he would like to thank the author, and I am sure a good many others join me, for the great care that he has taken in putting his paper together, and it is to my mind of very great value, as he has taken the trouble to give the results of the labors of a great many people in various parts of the world, and anyone troubled with the same conditions has got a good deal of help carefully collected together. I should like to read an account of the extraordinary forces of waves as experienced in Scotland, as given in " The Construction of Harbours " (by Thos. Stevenson). It gives a good idea of what some of the structures have got to withstand, which the author has on some of those diagrams :—

"EXTRAORDINARY FORCE OF THE SEA AT WICK BREAKWATER.—When we wish to ascertain what is the greatest feat that has been achieved by the waves, we naturally look to the ravages which are to be discovered in the rocky cliffs which confront the ocean. We should never expect that examples of the development of the *greatest* force would be found to be against the masonry of those artificial works which form our ports and harbors. The enormous extent and endless variety of exposure of the shores of Britain, as compared with those of the few piers or breakwaters erected here and there along the line of coast, make it to the last degree improbable that the maximum results should be found anywhere else than among the rocks *in situ* on the shore. Accordingly, the examples of the most violent wave-action which have just been mentioned, and which were all that were given in the first edition of this book, were cases of the destruction or movement of dislocated natural rocks This, however, no longer holds true. The most startling example now on record is that of an artificial work. The harbor works at Wick, which were for nine years in progress before they were abandoned, were commenced in 1863 and consisted of blocks of from 5 to 10 tons, set on edge, first built above high-water neap tides with hydraulic lime, then with Roman, and latterly with Portland cement. In October, 1864, 300 feet of the contractor's staging were carried away; and greenheart was afterwards substituted for memel piles. The depth under low-water springs in which the first portion of the wall was founded was 12 feet, in conformity with universal practice; but 18 feet was afterwards adopted, which was a fortunate precaution, for in 1868 the rubble was washed down to 15 feet below low-water, and serious damage occurred to a part of the superstructure. In 1870 a length of 380 feet (about a third of the whole) was destroyed. In February, 1872, after the superstructure had been rebuilt solid with Portland cement, a new species of damage took place, the face stones being in many places shattered by the sea which is all the more remarkable from the fact that the blocks were of the same density as granite, and of a strength three times greater than that of Craigleith stone—a phenomenon, indeed, unparalleled in the history of sea works. In December, 1872, a further proof of force was manifested, and is thus given in the words a report by Messrs. Stevenson 'The (seaward) end of the work, as has been explained, was protected by a mass of cement rubble work. It was composed of three courses of large blocks of 80 to 100 tons, which were deposited as a foundation (in a trench made) in the rubble. Above this formation there were three courses of large stones carefully set in cement, and the whole was surmounted by a large monolith of cement rubble measuring about 26 feet by 45 feet by 11 feet in thickness, weighing upwards of 800 tons. This block was built *in situ*. As a further precaution, iron rods, 3½ inches diameter, were fixed in the uppermost of the foundation courses of cement rubble. These rods were carried through the courses of stone work by holes cut in the stone, and were finally embedded in the monolithic mass which formed the upper portion of the pier. Incredible as it may seem, the huge mass succumbed to the force of the waves, and Mr. M'Donald, the resident engineer, actually saw it from the adjacent cliff being gradually 'slewed' round by successive strokes, until it was finally removed, and deposited inside of the pier. It was not for some days after that any examination could be made of this singular phenomenon, but the result of the examination only gave rise to increased amazement at the feat the waves had achieved. It was found on examination by diving that the 800-ton monolith forming the upper portion of the pier, which the resident engineer had seen in the act of being washed away, had carried with it the whole of the lower courses which were attached to it by the iron bolts, and that this enormous mass, weighing not less than 1,350 tons, had been removed *en masse*, and was resting entire on the rubble at the side of the pier, having sustained no damage but a slight fracture at the edges. A further examination also disclosed the fact that the lower or foundation course of 80-ton blocks, which were laid on the rubble, retained their positions unmoved. The second course of cement blocks, on which the 1,350 tons rested, had been

swept off after being relieved from the superincumbent weight, and some of them were found entire near the head of the breakwater. The removal of this protection left the end of the work open, and the storm, which continued to rage for some days after the destruction of the cement rubble defence, carried away about 150 feet of the masonry (one-seventh of the whole), which had been built solid and set in cement. The same remarkable feature of former damage was strikingly apparent in the last damage—*The foundations, even to the outer extremity of the work, remaining uninjured.*' Extraordinary as this may appear, it was surpassed in 1877, when another concrete mass, which had been substituted for the one that was moved, was in like manner carried away, though it contained 1,500 cubic yards of cement rubble, the weight of which was about 2,600 tons."

That, gentlemen, gives you an idea of what you are up against when you are tackling the forces of nature. In the Isle of Man a similar solid concrete pier was built for the protection of the fishing fleet. I have never seen it, but I have read of it. Nature destroyed it in a similar way and it collapsed into smaller blocks. The people in the Isle of Man are rather poor, and they could not afford to build another structure, but it was found that, although it was broken, it served its purpose, as it broke the force of the waves. After that, the same engineers in designing a work in Cumberland took the lesson from Nature and built a higgledy-piggledy system, very much the same as you have in your Moles at Fremantle, and it was found that that resisted and broke up the force of the storms better than a big surface exposed to the forces. With regard to one of the sea walls at Blackpool, shown on the diagram, I cannot help but regard the ashlar with joints as an entire waste of money. I think it would be far more satisfactory and a sounder job with a concrete face, and in addition a good deal more economical, both in first cost and maintenance.

Mr. A. J. Hillman said the subject of the periodicity of waves is rather an interesting one. I think most of us would be grateful to the author if he had any figures showing whether the periodicity of waves varies from time to time during storms—whether more waves, for instance, come on shore per minute during a heavy storm than during ordinary sea weather; and some figures, for instance, as to how many waves *do* come on shore. I can remember on one occasion counting six or seven per minute. Does that vary at different times? In one small paragraph the author just mentions the subject of periodicity; and perhaps he can tell us a little more about it. It is only a small point, but it struck me, and I thought I would put it before the meeting.

Mr. T. M. Carey said Mr. Ridgway's paper was of very great interest to him, as he felt sure it must have been to every member of the Institution. There is one point in the paper which I wish to mention, that is in regard to the method of protecting the wall from destructive wave action by constructing projections or dentals on its face to break the returning wave and so diminish its effective force. The idea seems to be a good one, but

I should like to know whether the enormous forces exerted by the waves in rough weather have the effect of wearing or breaking off the dentals to any great extent.

MR. J. R. W. GARDAM said, one thing I would like to ask Mr. Ridgway, (probably it has been tried, but it seems to me that the general form of sea wall is designed to take the full force of the waves): Why not build a palisaded wall to break it, like the wind-break breaks the force of the wind at Fremantle? In several other cases where we have to break great powers we do not try to do it all at once, but gradually. It seems to me that an endeavor might be made to break the force more gently than by presenting a blank wall to the full force of the waves. I would like to know if anything of that nature has been tried.

MR. RIDGWAY in reply said Mr. Ramsbotham's remarks were very interesting indeed. I think that the wall he referred to was at Wick, in Scotland, and it seems to me that what he read is very much to the point, but the more so I think because at that time all wave force was considered to be what one might term direct force only. But we see that Professor Gibson has recently demonstrated that there is not only direct force due to wave impact, but also the possibility of greater forces due to compressed air and water hammer. Water hammer is by a long way the most severe. I think Mr. Ramsbotham said that the structure was built of blocks of cement rubble. It is noteworthy that the upper blocks and the larger middle blocks were shifted, while the lower blocks remained intact. This result seems to point to the fact that air or water hammer action was to some extent at least responsible for the collapse of the breakwater, for the upper and middle blocks would most probably have their joints exposed between successive waves and consequently be subject to these forces. In connection with the Isle of Man, where Mr. Ramsbotham said that another wall was built and subsequently collapsed, it may be that this wall also was broken down as a result of the same forces. But then, when it is broken down, one finds that it becomes stable, like the Fremantle Mole. This, of course, is because a rubble structure can only be subject to a direct wave force. The cases of Wick and of the Isle of Man are very interesting and I think they go to prove that water hammer action does exist, and consequently that in designing any structures one wants to bear this in mind and either drain the structure efficiently, if blocks are used, or, if mass concrete, to make the structure so heavy that it is impossible to break it up even if as a result of cracks appearing in the concrete water-hammer action does eventually take place. Mr. Hillman refers to the perodicity of waves. I am afraid I cannot off-hand give him any figures, but I would refer him to the book I mentioned, viz., " Waves of the Sea," by Dr. Vaughan Cornish, which is very good. Observations show how the number of waves per minute passing a fixed point increase in shallow water, where the wave length is short. The

relation existing between wave length and period in deep water may be conveniently expressed by the equation wave length $= 5\frac{1}{8}$ x square of period (where period equals time in seconds which elapse between two succeeding wave crests passing a fixed point) Mr. Carey mentions about dentals and the life of the same. The dentals on the Wallasey Embankment new work, in Cheshire, have been on since 1895 and, as far as I know, only a few of them—probably not more than one dozen—have been broken off in that time, and these as a result of wreckage striking them. The newer lower portion of this wall is not fully exposed as yet, but the upper dental is exposed, and none of these have as yet been broken off. There is a possibility that they may be broken off and that is one reason why I advocate that a wall might be stepped because there is little fear of any damage. But the damage, as Mr. Carey will see, is trifling, and when it occurs such damage can be very easily repaired. The last gentleman in speaking mentioned the possibility of dealing with waves in very much the same way as one might deal with wind. That is the ideal way to do it. The difficulty is to know how to achieve the result. It does not much matter if some portion of the wind does go through your wind screen, but it does matter if a portion of the wave goes through your wall. For one has to remember that the filling at the back of the wall has to be protected just as much as the foreshore at the foot of the wall, and as a consequence a rubble wall such as is used at Fremantle, is not as a rule suitable for coast protection, and especially is this so in tidal waters. Consequently a compromise has to be effected and this is best achieved by the judicious use of some form of surface projection, or else by stepping the face of the wall. The wave is thus broken up and the momentum of its upward and downward rush destroyed. Of course, if the sea wall is really intended to act as a breakwater then the cases cited by Mr. Ramsbotham clearly show how efficient the rubble form of construction is for this particular purpose, but the difficulty is to apply this method to coast protection, and in the majority of cases it is not feasible.

SOME ASPECTS OF ENGINEERING AS APPLIED TO AGRICULTURE.

(By H. Oldham.)

I have selected for my paper two only of the many modern machines which are in use in connection with the agricultural industry. In each case the machine with which I am dealing is novel (so far as this State is concerned), and there is a point of common interest in so far as that both machines are self-propelling and each has its track laying appliances, which (so far as the requirements of the particular machine is concerned) successfully overcome the difficulties of self-propulsion over soft or sandy ground.

The first machine to be described is a steam scrub rolling plant, which the author has recently equipped to deal with the immense tract of mallee, mallet and moort scrub in the southern portions of the wheat belt. In most cases this vegetation is very dense (Plate 1) and the ordinary methods of clearing are so slow and costly as to be quite prohibitive. It was desired to encompass some means whereby this area could be quickly brought under cultivation, and this plant is the outcome.

The general arrangement of the apparatus is as follows (Plate 2) :— The motive power is an ordinary traction engine of 8 nom. h.p., fitted with attachments to the wheels, described later on. The engine is a Fowler compound, carrying 140 lbs. steam. A large spreader is drawn by steel wire cables. The spreader consists of a 9 x 7 steel H girder, 40 ft. long, mounted on a pair of old traction engine wheels, 6 ft. diameter, with 5 in. axles bolted on to the spreader. When in lighter timber, an extension piece 20 ft. long is attached to one end. This is an 8 x 6 H girder, and has a lighter type wheel on the outer end. To the spreader are hung two rollers 25 ft. long and 3 ft. 6 in. diameter ; these are built of ⅜ in. steel plates, and have an axle fixed in bearings at each end. The spread of the rollers is about 66 ft. when in widest position.

The rollers are simply equipped (Plate 3). There is a cross put in at the end, of boiler plate, with a bearing in the centre. An inside bearing on a similar cross is placed about 3 ft. inside the roller. The axles are simply 4 in. steel rods bent to a right-angle. The axle is slipped into the bearings. There is a shackle placed on the other end. That axle is not fast in any way and is fitted in that way particularly so that it will pull out if anything happens. If a rope happens to break no harm will come to the roller. The other axle will pull out and there be no further breakage.

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*For plates see end of book.

Anyone familiar with the limitations of the traction engine will of course admit that to attempt such work as this with the ordinary wheels would be absurd, because a traction engine is only really useful for hauling purposes, when on good roads. In which case it is possible to convert a great proportion of the power of the machine into useful work, while on bad roads or heavy ground it sometimes becomes impossible for an engine of this sort to do more than propel itself.

The attachments which are placed upon the wheels have been designed to remove this disability. These will be shown in detail later on.

Plates 4, 5 & 6 show the altered traction wheel. The separate tyres and flanges can be seen. The main point about the separate tyres and flanges is that they are simply shrunk on, and if there is undue wear in any part it is a very easy matter to remove the particular member and put on another one. The channels are built up first by cutting the slats off the wheel, then by putting on a filler of ⅜ in. plate, which extends right across the wheel, but is put on in two sections. This is held in position with a twitch until the first tyre is shrunk on. Then the tyres and flanges are put on in sequence all by the method of shrinking.

Plates 7 and 8 show the formation of a bearer, of which there are eight on each wheel. Two pieces of 60 lb. rail are rivetted to a steel plate, a piece cut out of the web and the end turned round, making a sort of sled about 4 ft. 6 in. long and a little over 12 in. wide. That is attached to the wheel in the channels shown on Plate I. It is attached by wire ropes. There is a bolt put through at each end and the necessary connections strung on to the bolt to take the wire ropes.

Plate 9 is a diagramatic form of the arrangement. The treads are shown in black on the near side of the wheel, and those in broken lines are on the far side of the wheel. The attachment is made by taking two ropes from one end of the tread and one rope from the other end; these are crossed under the bearer and attached to the wheel by a take-up hook that can be strained up. Each tread is simply strung on to the wheel and is not hinged in the ordinary way. When the tread is either on top or below the wheel it occupies a symmetrically central position. When it is coming down over the wheel its weight pulls it out and the ropes cross below the centre of the tread. Coming further down, as shown in dotted lines, they overlap more. It will be seen that as the wheel revolves these treads automatically come into the best position for the wheel to take them. They pick up in the same way. When they come to the top they come into a central position. The principle is, of course, limited in application, as regards speed. It will be seen at once that an arrangement of that sort would flog very considerably if any great speed were attempted, but at a pace of one and a-half or two miles they are quite safe. The machine is always running on a set of

rails. Furthermore, unlike a locomotive, it is attached to the rails, and if through any extra heavy pull the wheel tends to slip, a pull is immediately put on the two attaching wire ropes and the machine draws itself along to the end of the tread. There are eight treads on the wheel, in order that there may be always one in a practically central position under the wheel.

The traction engine used had to be adapted to suit the circumstances. (Plate 10). There is a very heavy pull on the engine at times and under ordinary arrangement the ordinary traction engine, with the wheels right underneath the front of the boiler, is rather apt to rear. Furthermore, it is necessary to get the axle and wheels well in front in order to keep the scrub away from the engine, because it must be remembered that even in the thickest scrub the engine drives direct into it. Most scrub rolling plants are designed on the side-pull arrangement, similar, for instance, to the arrangement of a reaper and binder where the power is applied along the line last cut ; but with this machine it is necessary to go straight into the scrub. Now, this machine was altered to this extent that a bracket was put on to the front of the engine and the king-pins lengthened somewhat in order to bring the boiler horizontal.

Plates 11 and 12 give an idea of the work done. Members will see the size of the timber in the foreground. This is moort timber, running up to about 40 ft.

The view taken is of one run of the scrub roller. It is about 58 ft. wide. The machine simply went through that once and produced the result shown. As will be seen, the timber is very thick. The timber on the near side of the picture was too dense for anybody to walk through.

Performance of Plant.

With these attachments the engine requires only a few pounds of steam when running light. She develops about 45 horse-power, and at least 40 horse-power is available for tractive purposes. The plant has rolled as much as five acres per hour with a water consumption of about eighty gallons.

It has been found that one man would take five weeks to cut the timber on a similar area, consequently the gain in speed of operations is enormous. Two men are required to run the plant, exclusvie of water carting, and the total cost per day for actual rolling only amounts to a few shillings. The plant rolls the scrub down in a thick mat, which is the exact condition required for successful burning off.

There is a large demand for this work and two more plants are now about ready to put in commission. It is certain that twelve months hence there will be a new agricultural territory added to the wheat lands of the State through the agency of these machines.

This completes the description of the machine, which embodies the first type of track laying attachment.

The second machine is designed for entirely different work. It has been recently imported by the Government for use in connection with the drainage works in the south-west of this State, including the laying of agricultural drain pipes. The plant is termed the Austin Ditcher.

Plate 13 gives a perspective view of the machine. It is to all intents a land dredge, mounted on a pair of catterpillar platforms and driven by a 40 horse-power petrol engine. It can make a trench 16 ft. deep with vertical sides. There are buckets arranged exactly like a dredge on a chain of big links. The ladder is raised and lowered by a temper screw The top of the screw can be seen above the machine. That is worked by the main engine by an ordinary arrangement of double bevel gear ; one set raises, and the other set lowers. The point of the machine, with the tumbler on it, is raised or lowered into the ground. The main part of the gear is on the after part of the machine, over the catterpillar platforms.

The engine mounted forward drives a fore and aft shaft, which is connected with bevel gear to a cross shaft, carrying a pulley, which belt drives a pulley on the main gear. There is a chain drive for the dredge part of the machine. There is nothing particular about the steering arrangements. The buckets (Plate 14) are of the open type and there is a positive cleaning arrangement below the top tumbler, which wipes out each bucket as it passes. The material drops on to a transverse belt, the end of which is shown. This belt can be run out or back as is required and delivers on either side. Of course, with various classes of material it is necessary to vary the traversing speed. That is done by changes of gear. There are several sets of gear, that can be altered to suit the particular class of country in which the machine is working.

Plates 15 and 16 illustrate the catterpillar platform, formed of Oregon sections plated on the bottom and connected each by three links, a link near each end, and a heavy central link, open in the centre, to receive a sprocket driving wheel. The driving wheel is simply a big sprocket wheel driving in the centre link. There are two plain idler wheels and one sprocket idler. Throughout this machine all the heavy wearing parts, such as the pins on the excavating portion of the machine and those on the catterpillar platform are of manganese steel. The job, like most American plants, is fairly roughly finished, but the material appears to be very first-class. The platform is about 4 ft. long and about 2 ft. wide.

The main point about the buckets is that they have three manganees steel teeth, which do the heavy work. The bucket brings up its load and there is a heavy wiper, roughly shaped to the bucket, which runs through it as it turns on the top of the tumbler, and in that way causes it to be

absolutely positive emptying. The wiper is fixed with a spring connection so that it will give during the run through, in case it strikes anything very hard, to prevent any breaks. Members will see, of course, that so far as the plant has been described it will cut only a vertical-sided trench, but there are side cutter attachments which have a batter of half to one. Those are put on to the main ladder and they are operative for about six feet deep. That is, if a trench is required up to six feet deep it can be battered. Anything below that is straight-sided. That is a drawback in some cases, but in most of the South-West lands the drains that have already been cut there, *i.e.*, the smaller size drains, are all practically straight-sided.

There are three changes of buckets. The smaller size is 15 inches across and the larger is 26; consequently, it can be seen that a fairly big channel can be cut if required by putting on the large-sized buckets and spreading out the side cutters as far as they will go.

There is a further arrangement which has not been obtained with this machine, but which, according to all reports, is very useful. The machine, amongst other things, is useful for cutting trenches, for laying agricultural drain pipes. The attachment is a flexible tube through which the drain pipe is served down into position as the machine works along. There is a semicircular tooth put in the centre of each bucket, the size of which conforms to the size of the drain pipe to be laid. That cuts a small semicircular gullet in the bottom of the drain, and the pipe runs into that. So far that portion of the machine has not been applied, but it is proposed to obtain one and use it. This machine has only just been put into commission, but there is no doubt of the suitability of the design

There has been no difficulty in conveying the machine along very wet ground indeed. In several cases where it has had to be shifted for some miles, there are places where drays have been bogged and traction engines have also sunk right down, but this machine has been able to travel over the top.

It therefore appears that this particular type of self-laying track is also going to be of great use. I think there is very little doubt that it will be availed of very largely in this State.

A similar plant in South Australia has demonstrated the possibility of excavating ditches at a cost of 2½d. per cubic yard, inclusive of depreciation and all other charges. So far as the plant has been tried it shows a marvellous speed in excavating.

Detailed Description of Plates.

Plate 1.—Moort Scrub. These trees are in many cases 30 to 40 feet high. This is a fairly good sample. It will be seen that it would be rather a difficult matter to take an ordinary traction engine or other engine through that without any gearing behind it.

Plate 2 shows the general arrangement of the plant. The traction engine drawing a girder 50 feet long made up in two parts. There are traction engine wheels—old wheels on each end. These are put on two axles which are bolted on to the web of the girder. This shorter girder is a smaller one and the arrangement as shown there is for the plant in use on the lighter types of scrub. When very heavy scrub is taken this big spreader is used by itself. As will be seen there are two rollers which are hung to the girder. Each of those rollers are 25 feet long, they are 3 ft. 6 in. in diameter and are built of $\frac{3}{8}$ in. boiler plate. The engine is equipped specially for the purpose with track laying apparatus.

Plate 3 —This is an end view of the rollers just as they are constructed. They are very simply equipped. There is a cross put in at the end, of boiler plate, with a bearing in the centre. An inside bearing on a similar cross is apparent at the end of my stick. The axles are simply 4 in steel rods bent to a right-angle. The axle is slipped into the bearings. There is a shackle placed on the other end. That axle is not fast in any way and is fitted in that way particularly so that it will pull out if anything happens. If a rope happens to break no harm will come to the roller. The other axle will pull out and there be no further breakage.

Plate 4 —You will see this is the traction engine. The treads which are used in connection with the work are shown on the wheel. There are eight of these threads, which I will illustrate later on. Four of them are on each side of the wheel, which is divided into two channels. There are four on this side and four on that. I would draw attention to the timber buffer, which is bolted in front of the engine to protect the smoke stack and cylinders. That can be seen dimly. That is simply a big log that is bolted in front in order to breast the timber and prevent it interfering with the front part of the engine. A later design is rather more elaborate, but the same principle exists.

Plate 5.—This is a photo. of the wheel. It will be remembered that an ordinary traction engine is fitted with diagonal slats. Those have to be cut off and the wheel is built up in the form shown—together by the shrinking on of tyres. There are four tyres and four flanges. The next illustration will show that more clearly.

Plate 6.—The tyre can be seen here. There is a corresponding tyre just inside that flange. There is a slight break and then two more tyres. The result is hat the wheel is divided into two distinct channels. It

might have been possible, of course, to bend channel iron and put it on to a wheel and get something like the same result. The point about the separate tyres and flanges is that they are simply shrunk on and they stay on very well, but if there is undue wear in any part it is a very easy matter to remove the particular member and put on another one. That is all built up first by cutting the slats off the wheel, then by putting a filler of ⅜ in. plate, which extends right across the wheel, but is put on in two sections. That is held in position with a twitch until the first tyre is shrunk on. Then the tyres and flanges are put on in sequence all by the method of shrinking. The main point which I wish to illustrate is that there are two distinct channels with a tyre for a rail to bear on on each side of each channel and with flanges to prevent the treads from coming off.

Plate 7.—That is a view of one of the treads; and this is the bole of a 60 lb. rail. The two rails are riveted to a plate, which we will see better in the next plate.

Plate 8.—You can see the rail plate at the bottom and slats riveted underneath. The end is turned up. The piece cut out of the flange of the rail and the web and the end turned round, making a sort of sled about 4 ft. 6 in. long and a little over 12 in. wide. That is attached to the wheel in the channel which I have shown. It is attached by wire ropes. There is a hole put through at each end and the necessary connections strung on to the bolt to take the wire ropes.

Plate 9.—This is a diagramatic form of the arrangement. The treads of the threads shows in black rails on the inside of the wheel and those in broken lines are on the far side of the wheel. Four of the broken lines and four of the firm lines. The attachment is made by taking two ropes from the end of this tread, running them round the wheel and through the wheel at a point about here. Those are simply rings and attached to hooks at each end. The hook inside the wheel is a take-up hook that can be strained up to keep the hook closed. There are two others at this end. They cross the pair I described and also made fast through the wheel, so that each tread is simply strung on to the wheel and is not hinged in the ordinary way. When the tread is either on top or below the wheel it occupies a symmetrically central position. When it is coming down over the wheel its weight pulls it out and the ropes cross below the centre of the tread. Coming further down, as shown on that dotted line, they overlap more. The crossing of the ropes overlaps further from the centre, so that it will be seen that as the wheel revolves those treads automatically come into the best position for the wheel to take them. They pick up in the same way. When they come to the top they come into a central position. That is the whole arrangement as regards the tread. They are, of course, limited in application as regards speed. It will be seen at once that an arragnement of that sort would flog very

considerably if any great speed were attempted, but at a pace of 1½ or 2 miles they are quite safe. It will also be noticed that by the arrangement the machine is always running on a set of rails. Furthermore, and like a locomotive, it is attached to the rails, because if through any extra heavy pull the wheel tends to slip a pull is immediately put on the two wire ropes running to this end and the machine draws itself along to the end of the tread. There are eight treads on the wheel, in order that there may be always one in a practically central position to the wheel. It will be seen that one tread is just coming under the wheel, while another one is going out and one is right under. With the arrangement of eight treads to each wheel the machine is always right on the top of a first-class road. There is, of course, ample bearing provided by the tread.

Plate 10.—The traction engine which was used had to be adapted to suit the circumstances. There is a very heavy pull on the engine at times and under ordinary arrangement the ordinary traction engine with the wheels right underneath the front of the boiler, is rather apt to rear Furthermore it is necessary to get the axle and wheels well in front in order to keep the scrub away from the engine, because it must be remembered that even in the thickest scrub the engine drives direct into it. Most scrub rolling plants are designed on the side-pull arrangement, similar, for instance, to the arrangement of a reaper and binder, where the power is applied along the line last cut ; but with this machine it is necessary to go straight into the scrub. Now this machine was altered to this extent, that a bracket was put on to the front of the engine, another bracket here, lengthened somewhat in order to bring the boiler horizontal. There was a certain amount of distortion from the horizontal caused by placing the engine upon the treads. This bracket was made sufficiently high to bring this end of the engine up and the bolt goes to this bracket.

Plate 11.—This gives some idea of the work done. Members will see the size of the timber here in the foreground. This is moort timber, running up to about 40 ft.

Plate 12.—This is a view taken of one run of the scrub roller. It is about 58 ft. wide. The machine simply went through that once and produced that result. As will be seen, the timber is very thick. This timber on this side was too thick for anybody to walk through. It would be a difficult matter to walk through any of that. That represents the heavier type of work which is to be done.

Plate 13.—The Austin Ditcher. It is to all intents and purposes a land dredge. It is mounted on a pair of caterpillar platforms and driven by a 40 horse-power petrol engine. It can make a trench 16 ft. deep with vertical sides. This is the ladder. There are buckets arranged exactly like a dredge on a chain of big links. The ladder is raised and lowered by a temper screw. The top of the screw can be seen above the machine. That is worked by the main engine by bevel gear The

ordinary arrangement of bevel gear, so that one side runs forward and the other side lowers. The point of the machine, with the tumbler on it, is raised or lowered into the ground. The main part of the gear is forward gear, on the after part of the machine rather over the catterpillar platforms.

Plate 14.—This is the bucket. The main point about it is that it has manganese steel teeth. Three teeth bolted on. Those do the heavy work. The bucket, as I have said before, is an open bucket. It simply brings up its load and there is a heavy wiper, roughly shaped to the bucket, which runs through the bucket as it turns on the top of the tumbler, and in that way, of course, it is absolutely positive emptying. The cleaner is fixed with a spring connection, so that it will give during the run through, in case it strikes anything very hard, to prevent any breaks. Members will see, of course, that so far as the plant has been described it will cut only a vertical sided trench, but there are side cutter attachments which have a batter of half to one. Those are put on to the main ladder and they are operative for about six feet deep. That is if a trench is required up to six feet deep it can be battered. Anything below that is straight sided. That is a drawback in some cases, but in most of the south-west lands the drains that have already been cut there are the smaller size drains which are all practically straight sided. There are three changes of buckets. The smaller size is 15 inches across and the larger is 26; consequently it can be seen that a fairly big channel can be cut if required by putting on the large sized buckets and spreading out the side cutters as far as they will go. Members will see that the side cutter simply draws behind and slices off on both sides of the trench which is already cut.

Plate 15.—This is one view of the catterpillar platform. The engine is mounted here, drives a 4½ in. shaft, which is connected with bevel gear to a cross shaft. The driving belt is on the other side of the machine. A chain can be seen here, which is the chain drive for the dredge part of the machine. The steering: there is nothing particular out of the way about that—the ordinary steering arrangements. The excavated material is brought up by the buckets. They are of the open type and there is a positive cleaning arrangement at the top which wipes out each bucket as it passes. The material drops on to a transverse belt, the end of which is seen. That belt can be run out or back as is required and delivers out on either side. Of course with various classes of material it is necessary to vary the traversing speed. That is done by changed gear. There are several sets of gear in connection with this chain, which is the main driving chain, that can be altered to suit the particular class of country in which the machine is working.

Plate 16.—This illustrates another view of the catterpillar platform. There are oregon sections plated on the bottom and they are connected each by three links, a link near each end, and a heavy central link, open

in the centre, to receive a sprocket driving wheel. The driving wheel is at this end simply a big sprocket wheel driving in the chain. The machine is driven by ordinary chain gear and I may say that throughout this machine all the heavy wearing parts, such as the pins on the excavating portion of the machine and those on the catterpillar platform, are of manganese steel. The job, like most American plants, is fairly roughly finished, but the material appears to be very first-class. That platform is about 4 ft. long and about 2 ft. wide.

There is a further arrangement which has not been obtained with this machine, but which, according to all reports, is very useful. The machine, amongst other things, is useful for cutting trenches, for laying agricultural drain pipes. The attachment is a flexible tube through which the drain pipe is served down into position as the machine works along There is a semi-circular tooth put in the centre of each bucket, the size of which conforms to the sizes of the drain pipe to be laid. That cuts a smaller semicircular opening in the bottom of the drain and the pipe runs into that. So far that portion of the machine has not been applied, but it is proposed to obtain one and use it. This machine has only just been put into commission, but there is no doubt of the suitability of the design. There has been no difficulty in conveying the machine from very wet ground indeed. In several cases, where it has had to be shifted for some miles, there are places where drays have been bogged and traction engines have also sunk right down, this machine has been able to travel over the top. So far as means of propulsion, it appears that this particular type of self-laying track is also going to be of great use. I think there is very little doubt that it will be availed of very largely in this State.

Discussion.

Mr. J. F. Ramsbotham said he would like to ask whether brake or indicated horse power is referred to for the dredger for excavating drains. Then I notice that the buckets have three manganese steel teeth. Those teeth were tried in England for a dredger, certainly with greater horse power, and were found unsuccessful as they damaged the lips of the buckets underneath ; the teeth pulled out. I should also like to ask what is the capacity of the buckets on the dredger, because the price given strikes me as very low indeed—so low, in fact, that it is lower than any price we have done in England, where labor was not half so expensive and working in an open excavation. I think the lowest we ever had was 4d. per yard. The dredging of mud, the easiest and best dredging we had was 1½d. per yard. I should also like to ask if the dredger has variable speeds for dredging in hard or soft material. The buckets that we had were 20 cu. ft. for hard material and 54 cu. ft. for soft material so that makes the price per cubic yard seem all the lower. I enjoyed very much listening to the paper and certainly the interest was very considerably added to by the slides.

MR. W. H. SHIELDS said he could not quite grasp the idea of the fixing of the treads.

MR. J. W. R. GARDAM said he would like to ask Mr. Oldham, in the matter of dredging, whether this most interesting but at the same time elaborate contrivance of a sea dredge on land is as successful as the methods they are adopting in the Eastern States, which is shooting out by explosives. It is quite simply done there—they only put a plug in there about every 10 ft., I suppose a succession of them, and the first shot, by concussion, fires the rest of the shots, and the ditch is very cheaply cut in that manner. I was wondering if he had heard anything of that explosive way of cutting ditches.

MR. H. OLDHAM, in replying to the various questions and remarks, said Mr. Ramsbotham wished to know what particular class of horse-power was quoted. That which I quoted was the brake horse-power. As regards the use of the manganese steel teeth, of course it is to be remembered that the buckets, as compared with the buckets on an ordinary sea dredge, are very small, and as is almost invariably the case, being very much smaller they are very much stouter in proportion. I do not think there would be any difficulty as regards the tearing out of the teeth. Again, the buckets are of very small capacity—not much more, I should say, that half a cubic foot. They are spaced pretty close and the chain travels very much faster than an ordinary dredge chain, the result being that the machine comes up in efficiency and output. Then as regards the question of feed or speed, there is only one speed on the chain, that is only one speed on the dredge chain, but there are several variations of speed as regards propulsion. Those, as I explained when giving the paper, are not made in the familiar way in connection with motor cars by automatic changes of speed, but gears on chains exactly like the chains here are found to be more useful in that way. Although most of the West Australian country varies somewhat in character, yet the machine of course moves pretty slowly and so far very little difficulty has been found in adjusting the speed to suit the different class of country, simply by the method of knocking off the existing wheels and putting on change gear to either accelerate or make the speed slower. As regards Mr. Shields' question regarding the fixing of the treads: those are slung on t the wheel. The action is that when the wheel turns and the tread comes here the crossing of the ropes is down here on the other point instead of in the centre. When it is underneath the crossing is in the middle. It will be seen when that wheel turns if there is any slip at all it very soon takes up on the two ropes that are pulling. There are two ropes, two drivers and a single rope to counteract. On the question raised by Mr. Gardam, comparing the method of dredging as compared with the shooting, I know the shooting method. Dynamite is being very largely used in those ways, also in a way we never dreamt of a few years ago, that is for shooting out holes to plant trees in. As far as I

understand, the difficulty in connection with the shooting of ditches is, of course, that it is difficult to arrange the plugs to shoot a good section of the ditch. It is simply a question of shooting out and straightening up afterwards. In clays it is to open up the soil and assist percolation to some extent. As to the question of cost, I saw the figures as regards the cost of the machine working in South Australia on the Murray Flats, and as far as I can see everything including depreciation and working, expenses, repairs, etc., was included. Those figures certainly showed the very low cost of 2d. a yard and I think it is quite possible. I think I shall be able to show with the machine I have in use the same thing can be done. Of course, there is a good deal of difference between this class of machine and a dredge. A dredge very often, working at a depth, say, of 20 or 30 ft. below the surface of the sea, could not be run fast even if it were designed to be running at a greater speed than usual. It is impossible to say what obstacle may be run against and there is a possibility of breakage, whereas in working in a trench where the cut of the bucket runs from the bottom of the trench to the top on the slope it is possible to adjust the teeth so that there is only a slight skimming. I think I shall be able to produce figures later on for the information of any person interested. Regarding those figures quoted, I fancy the thing can be done.

EARLY HISTORY OF THE FREMANTLE GRAVING DOCK.

(BY W. H. SHIELDS).

The author admits, while he may appear to claim certain designs, that any great conception to be highly successful must bear the stamp of many minds. A departmental work has in this direction possibilities upon which the private practitioner must always cast envious eyes, and on the work of the Fremantle Graving Dock all these sources have been availed of to the fullest extent. In this direction not only was the history, procedure and methods of construction, together with the resulting success or failure, both physically and commercially, of every dock ever constructed whereof a record could be found, carefully investigated, weighed and appropriated where thought advisable ; but the author was able to draw upon the hearty and sympathetic co-operation of his colleagues in the departments, besides the advice and help of those at the time responsible, namely, the late Mr. C. Y. O'Connor, his successor (Mr. Palmer), and the present Engineer-in-Chief, Mr. Thompson ; also the late Engineer for Harbors and Rivers, Mr. Dillon Bell.

Besides all these there was advice from such English experts as Messrs. Coode, Son & Matthews, and besides their written words on the subject the author had the privilege of being closeted for days with Mr. Napier Bell and with Sir Whately Eliot, during which time practically every detail of the work and methods of construction were discussed.

To Mr. Turnbull, who when the dock became a burning question in 1907 was specially named to carry out the designs in conjunction with the author, is due many a suggestion the result of much painstaking research.

The co-lateral branches were also undertaken by experts. When it came to the question of workshops, machinery, cranes, etc., besides having the written literature on the subject, Mr. Leslie (Past-President of this Institution) lent his valuable assistance and experience, to which Mr. Hume, the Chief Mechanical Engineer of the Railway Department, not only added his knowledge, experience and practical help, but became practically responsible for that part of the work as embodied in plans drawn up by Mr. Higgins.

In like manner the Government Electrician spent his time and talents on the electrical portions, such as cranes, capstans, lighting, pumping, etc., etc. ; while several of the best-known pump makers put in specifications for the pumps and pumping plant, accompanied by sketch plans showing the space required, etc.

All this is much as it should be and must give splendid results from a Government point of view ; but it has the defect that the individual becomes merged in the department, and in a certain measure loses his individuality.

Perhaps some day this difficulty may be overcome, so that the praise or blame will be distributed to all taking part in a design proportionately to their share therein.

Sir Whately Eliot also most generously gave his services voluntarily and without charge for the benefit of this State by keeping up a correspondence with and inviting the author to freely consult him on all sorts of proposals *re* the dock, both general and detail. Mr. Wentworth Shields, Engineer for Southampton, also freely rendered service, as did Mr. Waddel, Engineer at Barry, Mr. Thompson, Engineer of the U.S. Navy Yard, Boston, Mass., and others.

From the time the author took charge of the work in 1898 until he surrendered if about three years ago, the author always had the most intimate and friendly relations with the Engineer-in-Chief, Mr. Thompson; whereby the work was much facilitated, red tape being altogether avoided.

My thanks are due to the Public Works Department for the loan of plans, and to Messrs. Ruskin for photographing them at very short notice.

In considering a dock for any port, the first consideration is—Does the trade of the port warrant its construction ? And in this light, if Fremantle be compared with other ports the answer cannot be otherwise than favourable.

In the following table many of the ports are only a few miles from other ports with docks. Fremantle is absolutely isolated. (These figures are taken from the official files and are several years old, witn the exception of Fremantle, which is taken from the newspaper account of the latest report).

Southampton, 3,800,000 tons of shipping ..	5 docks over 350 ft. long. 2 docks under 350 ft. long. 5 slips. 5 gridirons.

On this basis, Fremantle should have at least 13 docks and slips.

Newport, 2,700,000 tons	5 docks over 350 ft. long. 2 docks under 350 ft. long. 1 gridiron.

Swansea, 2,500,000 tons................	4 docks over 350 ft. long. 5 docks under 350 ft. long. 1 gridiron.
Manchester, 2,000,000 tons	1 dry dock over 350 ft. long. 2 floating docks. Other docks quite near.
Glasgow, 4,300,000 tons	5 docks over 350 ft. long. 3 slips.
Leith, 2,000,000 tons	1 dock over 350 ft. long. 6 docks under 350 ft. long.
London, 19,100,000 tons	13 graving docks over 350 ft. long. 2 of them 846 ft. long. 15 dry docks under 350 ft. long. 3 slips.
Liverpool, 19,500,000 tons...............	15 dry docks over 350 ft. long 4 of which are over 900 ft. 7 docks under 350 ft. long. 1 slip. 2 gridirons. There are other docks close by.
Cardiff, 13,200,000 tons	9 docks over 350 ft. on floor. 4 docks under 350 ft. on floor. 2 floating docks. 2 slips. 2 gridirons.
Newcastle, including North and South Shields, 9,000,000 tons	10 docks over 350 ft. long. 12 docks under 350 ft. long. 8 floating docks. 15 slipways. 1 gridiron.
Hull, 4,700,000 tons	3 graving docks over 350 ft. long. 6 graving docks under 350 ft. long. 7 slips.
Grimsby, 1,700,000 tons	3 docks over 350 ft. long. 1 pontoon dock. 1 slip.

Melbourne, 6,500,000 tons	2 docks over 350 ft. long.
	1 dock under 350 ft. long.
	5 slipways.
Sydney, 5,900,000 tons	4 docks over 350 ft. long.
	4 floating docks.
	3 slips.

Mr. C. S. Palmer in his report of December 1st, 1904, points out that it is usual in the United Kingdom to provide one dock for every 180,000 tons calling at the port.

From the figures in the above table, it will be evident that were there other docks as close to Fremantle as Claremont, Perth or Rockingham, the Port would be quite justified in having as many as a dozen docks, whereas it has none.

How long can the traders and public of Western Australia afford to pay higher freights and insurance fees between Western Australia and Europe than those charged from Melbourne or Sydney to Europe? Because such must always be the case where it is impossible to effect repairs to a ship's hull locally.

Shortly after the opening of the bar had been started at Fremantle, the question of a graving dock was brought up by Mr. O'Connor asking the then resident engineer, Mr. Dillon Bell, to report on a site. About the end of 1894 Mr. Bell suggested building a wooden dock of jarrah, similar to some that had been built in the United States for about half the cost of stone docks. He proposed a site at Rous Head, the dock running straight in to the bank at about right-angles to the stream, the size proposed being 600 ft. by 100 ft.

In many old wet docks where land and wharfage were exceedingly valuable the dry docks were placed so as to occupy the least possible amount of wharf and were therefore put end on or facing a corner, the still water of the wet dock allowing the ships, which were then small, to enter in almost any direction. At that time in Fremantle land and frontages were of little value, while the rapidly growing size of ships, and the river currents, made it practically prohibitive for a ship to lie athwart the stream when entering a dock.

The proposal to build a timber dock, on the precedent of some built in the United States, where timber had only been used as a solid lining to a clay hole, without any necessity to make it water-tight, the entrance, of course, being of concrete was fallacious.

Fortunately, these two fallacies were foreseen by the then Engineer-in-Chief.

The English consulting engineers, Messrs. Coode, Son & Matthews, also agreed as to the unsuitability of timber for even a small dock in porous strata, such as exist at Fremantle.

It is probably now well known that wood-lined docks did not prove a success even where the strata were suitable, one having been burned and one or two collapsed, while the maintenance was so enormous that the timber was replaced by masonry.

The following information, gleaned from the *Scientific American*, is instructive :—

Cost of maintaining three stone docks from 1892 to 1899 ..... $4,543
Cost of maintaining three wooden docks from 1892 to 1899.... $426,073
Besides $600,000 spent on reconstructing that at Brooklyn.—

Scientific American, Oct. 20th, 1900.

Floating docks were at this time (early in 1895) also considered, but the idea was not very favorably received by the English consulting engineers on account of the difficulty of docking, painting, cleaning, and repairing the floating dock.

In July, 1895, Mr. O'Connor, when instructing Mr. Dillon Bell to have borings made over the proposed dock and slip site, after discussing the necessity for both, states, *inter alia* :—

" Will you, therefore, please have borings made accordingly on the area of the proposed reclamation near Rous Head . . . . . being probably the most convenient, and it seems to me that convenience of situation is almost the only point to be studied, as there is, I fancy, very little advantage as regards probable cost in any one site over any other."

The bores were put down under the charge of Mr. Frank Reed, and proved the rock near Rous Head to be what is known as a " coralline rag " interbedded with beds of seaweed and sand, with occasional small lenticular beds of clay, the whole being about as watertight as a good sponge.

Captain Russell, R.N., at that time harbor master at Fremantle (August, 1895), pointed out, as had already been done by Mr. O'Connor, that the slip and dock should be alongside of each other, and he (Capt. Russell) would prefer them nearly parallel to the root of the North Mole.

In July, 1896, Mr. Napier Bell entered upon his task of designing a graving dock for Fremantle.

About this time bores were completed at a site on the north side of the river just west of the Railway Bridge. These proved the strata to be sand for a depth of 100 feet below L.W.M., and where the sand was passed through it was found to be underlaid by mud. Mr. McDonald

who put down the bores, considered further borings a waste of money as he did not think a dock could be built there other than a wooden dock.

Mr. Napier Bell completed his plans, specification and report about the end of December, 1896.

The following extract is from Mr. Napier Bell's report :—

"The best site is on the south side just above the railway bridge. Here a dock might have been built on the solid limestone, and a deep channel dredged into your intended channel in the inner harbor ; but I presume that the bridge and the interests connected with the railway in its present position put this site out of the question.

"The site on the north side of the river near and below the railway bridge is sand for about 100 feet. . . . . There is ample room for all purposes and that is about all there is to recommend it. . . . . . I think it is likely that much trouble, expense and risk would be incurred in getting foundations on running sand under 38 feet of water. . . . . The *pumps would draw quantities of sand* with the pumped water. Such a state of things usually gives great trouble, causing the work to be undermined by the pumping necessary to keep the foundations dry during construction. This, although *sand is a good foundation if it is quiet and undisturbed*, great delay and cost might have to be incurred to get the foundations successfully laid, although if once that were done, no doubt the dock once made all would be right afterwards. . . . . . The site at Rous Head has also its defects, but I don't think they are so serious as might be met with at the bridge site.

"The defects are uncertainty of the strata, layers of sand and soft stone being intermixed and irregular, but as far as can be ascertained the foundations will all come on good hard limestone."

The dimensions of this design were as follows :—Length, 560 with caison on inner stop, 590 with caison on outer stop ; width of entrance, 80 ; depth on sill, 28.

In June, 1897, the Admiralty were approached for a subsidy, and in July Mr. Coode was asked to advise as to pumps ; while in the same month Messrs. Clark and Stanfield forwarded plans for a self-propelling floating dock capable of lifting a second-class cruiser.

The question of a floating dock had been a matter under discussion early in 1895, but had not at that time been favorably entertained by the Consulting Engineers. Messrs. J. W. Henderson and Captain Laurie had also in 1895 offered the Government an option over a second-hand floating dock then lying in Sydney Harbor.

Messrs. Coode, Son & Matthews advised the use of three 33-inch pumps with disks 6 ft. 6 in. in diameter of 165 revolutions per minute, capable of emptying the dock designed by Mr. Napier Bell, and containing

12,000,000 gallons, in four hours, the drainage pump to have a 4 ft. disk. each pump to be driven by one cylinder 20 in. diameter, 22 in. stroke, using steam at 100 lb. pressure per sq. in., furnished by three boilers 7 ft. 6 in. diameter, 30 ft. long, a 5 ft. boiler 20 ft. long serving for the drainage pump.

A discussion followed as to the advisability of using triple-expansion engines, but Messrs. Coode, Son & Matthews considered that the extra cost and complicity of triple-expansion engines did not warrant their use for a pumping plant running so intermittently as the pumping plant of a dock.

In November, 1897, the Lords Commissioners of the Admiralty expressed their thanks for the opportunity they had been given for considering the matter, but regretted that in view of the many serious expenses they had to meet at the present time they were unable to make a grant towards the undertaking. They were also of the opinion that a mercantile dock would probably meet all present naval requirements.

About the same time Mr. O'Connor wrote to Mr. Napier Bell a description of a method he had seen employed to construct a large dock at Glasgow, where the foundations were in very porous materials. He asks Mr. Napier Bell if he knows of or considers there is any special feature at Fremantle that would preclude the adoption of similar tactics with equally marked success for the site in sand near the upper end of the harbor. Mr. O'Connor pointed out that the evidence discovered at Fremantle points to a successful issue.

Briefly, the method employed was to—

1st. Dredge out the site ;

2nd. Lay concrete under water to form a light outer shell ;

3rd. Pump in sand and gravel, to lend stability ;

4th. Excavate in the sand and gravel filling a narrow strip across the dock, and after caulking the leaks in that strip to complete in the dry that strip of the dock ;

5th. Complete the dock by proceeding with another strip as soon as the last strip was complete.

It may here be remarked that except where there is a definite small hole that can be literally caulked, this stoppage of leaks could not be accomplished against a head of water or by trying to force grout down behind the leak while the water is kept down inside the excavation ; but is accomplished by enclosing the leak by a pipe, freely drained until its cement connection with the surrounding concrete has set. The drainage tube is then closed and the water allowed to find its own level in the caisson tube. Then and only then can cement be forced into the leak

through a small pipe inside the main pipe, and this must have time to set before the tube with the equilibrating column of water can be removed.

Sometimes in rock or other impervious medium a small spring or even soakage occurs, whose hydrostatic head cannot be reached within any reasonable height, and it has been found that the most economical and probably the most efficient method of dealing with such cases is to provide a permanent drainage tube and gutter to lead the water to the drainage pump sump.

On the 25th of January, 1898, Mr. O'Connor again wrote to Mr. Napier Bell, and points out that they are dredging sand at the site he proposed for the dock at Rous Head, hitherto supposed to be rock. He proceeds :—

" This, I think, shows how delusive it would be to suppose that an excavation for dock site at that place would be entirely in rock, and bears out what I always believed to be the case, that there are large fissures in this rock filled with sand, through which the water would come when we came to excavate the dock site, just as freely as through the sand at site proposed near railway bridge, and that being so, I cannot see where the advantage would come in of going to the extra expense of dredging dock site mostly through rock, as compared with the cost of dredging it where it is all sand."

Mr. Napier Bell, replying to Mr. O'Connor on February 21st, 1898, states, *inter alia*, that he still believed in the safety of the Rous Head site, *or* the south side above the railway bridge. He also remarked :—

" . . . . . Apart from my natural fear for recommending a foundation in 100 ft. of sand, I say that where there was any choice every engineer would choose the rock foundation in preference, and only if there was no choice would one tackle the sand. In the sand you must dredge out the required opening, leaving the water undisturbed ; then drive close sheet piling 30 ft. long without joint round and enclosing the entire structure ; pumping well caisson chamber, all enclosed ; then lay under water the entire bottom with thick concrete, and such concrete laid under water is poor stuff usually ; and then start to pump and during the pumping you must wall, strut and caulk the piling. When the pumping has lowered the water 10 ft. or so *the sand will pour* up between the piles and the rough concrete, *undermining* and cracking it, and through the cracks *more sand will flow up* with the water rising from the bottom and undermining the floor still more. .. . ."

Both authorities distinctly saw these points, with this difference, that while Mr. Napier Bell hoped from the hard nodules met in boring that the limestone bore some resemblance to the rock ordinarily called

by that name, and would consequently prove reasonably staunch, Mr. O'Connor distinctly saw that the rock would prove no easier to deal with than would a bed of pure sand 100 feet deep; in fact, he points out that the greater ease with which sand could be dredged would turn the balance in favor of the sand site. And the ridiculously low figure (compared to rock) at which sand can be dredged allowed, as will be seen subsequently, a very much safer not to say an absolutely safe method to be employed when adapting Mr. Napier Bell's design to a sand site. On the following clauses hang, therefore, for good or ill the whole history of the Fremantle dock, for they apply to any and all known sites in the immediate neighborhood of Fremantle :—

Mr. O'Connor, January 25th, 1898 :—"This, I think, shows how delusive it would be to suppose that an excavation for dock site at that place (Rous Head) would be entirely in rock, and bears out what I always believed to be the case, that there are large fissures in this rock, filled with sand, through which the water would come when we came to excavate the dock site just as freely as through the sand at site proposed near railway bridge."

Mr. Napier Bell, February 21st, 1898 :—"When the pumping has lowered the water 10 ft. or so *the sand will pour up* between the piles and the rough concrete, *undermining and cracking it,* and through the cracks *more sand will flow up with the water rising from the bottom undermining the floor still more.*"*

During the following eleven and a-half years, while the author was interested in the Fremantle dock in its various phases, proposed positions, and vicissitudes, these truths which thoroughly conformed with his own experience were never lost sight of, viz. :—

1st. That the water must remain undisturbed and quiescent during the deposition of the concrete shell;

2nd. That no pumping should be attempted until the outer shell was complete.

About this time Mr. Thompson instructed the author to amend Mr. Napier Bell's plans to suit the sand foundations below the railway bridge. This he proceeded to do (the late Mr. Frank Shenton acting as assistant); at the same time he pointed out that the dock designed by Mr. Napier Bell would be too small for the ships of the future.

The adaptation involved some extensive alterations, due to the porous nature of the strata. The pumping wells were grouped instead of distinct, to allow of being laid in the water as steel tubes protected outside and inside with cement concrete. The sliding caisson was

*This portion of Mr. Napier Bell's letter was meant to refer to the site below the Bridge, but may in conjunction with Mr. O'Connor's letter be used as advice as to how the sand would be pumped up at Rous Head, leaving caves in its stead.

replaced by a ship caisson, to save the walling involved in the caisson chamber, with its adherent difficulty its place being taken by a timber jetty berth. Also a leading wharf was substituted for dolphins, probably for the first time in the history of docks.

But the point of greatest interest in this dock was the proposed method of construction, the method of proceedure being—

1st. To dredge the site, forming a bank round three sides of it to ensure tranquil water.

2nd. An artificial bottom to be formed of clay dredged from Perth Water and transported in barges and rammed in position.

The cheapness of sand dredging permitted this luxury, which while giving weight in a much cheaper form than concrete would also furnish a watertight medium, for, as those of you who have much experience of concrete know, waterproofness is not among its strong points. Moreover, this clay permitted a poor concrete to be used where it was only needed for filling or foundation purposes, as for instance under the haunches of the invert.

3rd. The driving of piles to carry the working stage and traveller, where the mixing tables, etc., were situated and from which the depositing flume was to depend. These stages were to be numbered like twin scales, the traveller also being numbered like a scale, and also the flume, so that the exact position of the concrete deposited would always be known.

Sheet piling supported by the staging jetties was also to surround the dock. It was, moreover, intended to screen off with canvas the portion of the dock where the flume was depositing concrete. Canvas was also to be used over the floor to effectively separate the concrete and clay.

The reasons for adopting the tapered flume were—(1st) to prevent the concrete from coming in contact with the water until laid, and then only on its surface, and (2nd) to provide a column of concrete perhaps fifty feet high for pressure purposes, ensuring a compact and dense concrete.

The flume was to be of wood, be square in section, enlarging as it went down, the lower part having adjustable doors to permit of the concrete being left behind undisturbed as the flume advanced. A cheap temporary bottom would be used any time operations were suspended for any time, because the flume would have to be partially filled before touching the water, and then filled as it went down. When deposition

was started the temporary bottom would be abandoned and as the flume was made to advance it would be fed from above so that it would always remain approximately full.

After laying the outer shell of the floor, the outer shell of the walls would be laid in like manner, the sheet piling acting as a backing and as successive layers of concrete rose inside, clay would be deposited outside, backed by quarry refuse ; thus equilibrium would always be maintained instead of heavy and expensive shoring, and whenever possible the sheet piling would be withdrawn altogether to allow of the clay pressing against the concrete.

Finally, when the outer shell had been completed it was the intention to load the partially finished dock with quarry spalls and sand and proceed as at Glasgow.

All these processes may be much more readily gathered from the sketch plans shown by the lantern.

This proposal not only met with the approval of Mr. Thompson and Mr. O'Connor, but Messrs. Coode, Son & Matthews, in their letter to Mr. O'Connor dated the 29th June, 1898, approved of the method sketched out in his letter of the 23rd of May for building the dock below the railway bridge, and were just coming to the same conclusion, and suggest surrounding the whole site with a puddle wall contained between double sheet piling. They further point out that the least depth of water on the sill should not be less than 30 ft. to deal with large men-of-war.

They also point out that the difficulty previously mentioned in connection with the docking of floating docks has been overcome by Messrs. Clarke and Stanfield's invention of a self-docking dock.

In 1898 an English Company offered to equip and work a floating dock and the Government slip and workshops if the Government would dredge a berth for the dock and provide a berth for ships under repair while afloat, and also land for workshops, etc. The promoters suggested that in view of the lower freights and insurance fees likely to accrue owing to docking facilities being available, that the Government should subsidise the capital of the company for a period of not less than ten years at 5 per cent. Mr. Royce, then Resident Engineer for the Fremantle harbor works, reported on this proposal and made some very interesting comparisons between floating and masonry graving docks.

On the 20th March, 1901, Mr. O'Connor points out that if it is necessary to adopt a proposal to carry the north wharf right up to the bridge, the proposed dock site below the bridge would have to be abandoned and the dock and slip put elsewhere—probably further up the river. He shortly afterwards proposed a conference between the Hon. the Minister, the Under-Secretary, Mr. Thompson, Mr. Palmer, the Resident Engineer

for Fremantle Harbor Works, and himself regarding the Fremantle dock. However, Cabinet decided that wharfage should be provided on the north side up to the railway bridge with clear water where Mr. O'Connor thought the dock ought to be.

About the end of November, 1901, the Engineer for Harbors and Rivers (Mr. Thompson) reminded Mr. O'Connor that—

"A port which like Fremantle seems destined to receive the very largest class of vessels should, therefore, I consider, be capable of docking almost any vessel afloat, and the dock would therefore require to be about 750 ft. long with an 85 ft. entrance width, or, should the prospective future be provided for, these dimensions might be 850 ft. long with a 90 ft. entrance."

Permission was obtained to prepare designs for a subdivided dock 850 ft. long with an entrance width of 90 ft. Although 90 ft. would be wide enough for the then immediate future, the author was very anxious for greater width, because it seems unreasonable to suppose that shipowners will continue to be impeded by narrow dock entrances designed for ships of several generations ago, and while docks may readily be lengthened, it is out of the question to widen them. Financial reasons, however, debarring any greater width being authorised, the author had to content himself by making the entrance the prescribed 90 ft. wide, and as no definite position was given he made it 90 ft. wide on the bottom battered to 100 ft. wide at L.W.M., and, thanks to that precaution, the dock as designed would still admit a "Mauretania."

While dealing with the subject of the dimensions of docks it would perhaps be as well to look at some diagrams which the author prepared for the purpose of showing how steadily the dimensions of ships have grown, and by producing the curves the size of ship to expect at any future time, not more than a few years ahead, can be forecast with a reasonable degree of certainty. Only an occasional erratic departing any distance from the curve, such, for instance, as the "Great Eastern," which was nearly as far in advance of her time as her designer, Brunel, was beyond the ordinary engineer of his day in the matter of scientific knowledge.

Another of the diagrams, showing the ratio of beam to length, shows that pretty well all the Atlantic record-breakers have been wide vessels, in spite of the attempts made to gain speed at the expense of beam.

Finding that narrow ships did not give a steady platfrom for gun practice, Sir William White, experimenting on behalf of the Admiralty, found out that no increase of power was necessary to drive a ship with a beam up to one-sixth of her length; in fact, in a rough sea probably less power would propel a vessel of that beam than a narrower ship.

The result is that the "Dreadnought" was launched with a beam of one-sixth of her length. And this takes us back to one of the earliest records of ship building, an entry very similar to those now found in Lloyds' register being written, viz., length 300 cubits, breadth 50 cubits, depth 30 cubits.

Judge of the increased carrying power, not to mention comfort to the passengers, if the 600 ft. liner of to-day were 100 ft. wide instead of only 50 to 60 ft., according to the dock entrances at her ports of call. Is it any wonder that the "Lusitania" and "Mauretania" increased their beam to 88 ft. as against the 68 ft. of the Cunard company's previous greatest effort? And is it not to be expected that the 900 ft. liner of the future will have a beam of 150 ft., with the accompanying stability—and demand docks to suit? Why should ship owners be compelled to build a ship 800 ft. long to carry no more than a ship 600 ft. long could carry with her existing engines, were the dock entrances only made wide enough to receive a reasonably wide ship?

History does not relate how it happened, but in September, 1902, Mr. Leslie, in proposing the removal of the bridges, showed his proposal for placing the dock and slip in Rocky Bay in a position now occupied by a sand bank, as shown on the diagram. This sketch of Mr. Leslie's demands more than passing notice, and shows the benefit of many councillors.

It will be noticed that the dock has two entrances, one at each end. Now, a good many docks have been designed so that they could be used for dry docks when required, such as those at Tilbury, but probably never before had a graving dock designed for that purpose only had a double entrance, and the advantage is so evident for a large subdivided dock, in that it allows either end to be used without disturbing the vessel in the other as independently as if they were two distinct docks, that the author adopted the double end for all designs of a graving dock for Fremantle got out for various positions, with perhaps one exception, that being a one-ended one stuck in the corner of Rocky Bay, at the special request of Mr. Dillon Bell.

In a report dated October, 1902, Mr. Palmer recommended a floating dock to be placed in Rocky Bay.

In 1903 the Premier invited Mr. Keele, the Engineer for Harbors and Rivers employed by the Government of New South Wales, and Mr. Napier Bell to confer with the Engineer-in-Chief for Western Australia concerning the dock site. Mr. Napier Bell was too ill to leave New Zealand; so Mr. Keele came over by himself and prepared plans for a naval station in Freshwater Bay, with a dock at Point Walter, and a commercial dock at Butler's Hump.

Of Mr. Keele's visit the author has little personal knowledge, being absent at the time, but Mr. Keele's reports are interesting, the plan he prepared being screened for your benefit.

Among the dock designs for Fremantle for which the author prepared plans and estimates probably the most noteworthy were those at Point Brown and Rocky Bay, under similar conditions to those below the railway bridge preferred by Mr. O'Connor.

Mr. Rolland also prepared a sketch plan and estimate for the Rocky Bay site, which at one time was the approved dock site. Mr. Rolland's proposed method of procedure was to mould large blocks of concrete on land, approximating to the radial blocks of an arch, fill the joints with broken stone grouted with cement forced through a pipe leading to the bottom level of the blocks, the whole being laid on a levelled bed of concrete put down with a flume and levelled by an H girder, the sides to be built in like manner ; in fact, slabs the full height might be used for the sides if suitable precautions were taken.

Two other alternative proposals were also put forward by the author, not only with a view to providing a dock site below the bridges, but with the further object in view of providing facilities that would outweigh the high cost of wages here compared to those paid at Singapore or elsewhere.

In all floating docks besides the risk of straining or even wrecking the ship, and in many graving docks with shallow entrances ships have to practically strip before entering, cargo, coal and removable heavy gear being all landed, the ship then proceeding to some out-of-the-way corner there to be repaired, painted or scraped, as the case might require.

Now, at certain ports with high tides ships lie on the bottom or even on the gridiron alongside the quay when the tide is out, cargo and passengers going to and from the ship without hindrance ; and it struck the author that if Fremantle could give ships advantages not to be obtained elsewhere, by placing the dock in such a position that the ship could load or unload cargo and be painted or scraped or have ordinary repairs done at the same time, thus saving the loss of time usual to docking, and more than compensating for the high wages paid in Australia compared to England or Eastern countries, and by providing deep water on the keel blocks and entrance, ships could dock with their full cargo and equipment on board, thus saving the expense of unloading and reloading their cargo, coal, etc.

By placing the one side of the dock on the alignment of Victoria Quay extension close to Arthur's Head, the wharf acting as a leading wharf so that ships could berth right up to the dock entrance when required, the other end of the dock opening out towards the deep sea jetty through the present South Mole, a caisson berth and leading jetty screening the

gate from heavy waves, the south side of the leading jetty also acting as a repair berth for ships afloat, the diagram probably making the matter more intelligible than mere words. It will also be seen that the ordinary electric cranes could proceed along the wharf for use at the dock, or conversely. The dock was to be 910 ft. long by 100 ft. entrance, 33 ft. on side, subdivided, the cost without workshops or cranes being £210,000.

The other position was that recommended in the early days by the late Captain Russell, R.N. Here the slip has been built, the excavation for the dock dredged, to designs and plans prepared by the author, Mr. Carlin being in charge of the dredging and slip, the latter being a copy of the old slip.

Here the workshops were designed to be on an artificial island built upon the part of the old rock bar known as The Knuckle, originally left for a wave-breaker, thus always leaving one side of the dock free so that one side of the ship could be in the commercial harbor while the whole ship was in hospital. Access to the workshops from the land side would be over the caisson gates and also by a subway under the central caisson seat, while on the water side a deep-water repair wharf was to have been built, where ships could lie and come under the 150-ton crane if required.

It was this last site that Sir Whately Eliot came out to inspect. He quite grasped the porousness of the strata, but was quite confident that the methods proposed would prove successful, although he preferred the diving bell to the flume. He liked the clay envelope shown in the design for the site below the bridge, but had to abandon it finally on account of the cost of dredging much extra rock and the danger of the dock floating up if clay were substituted for the outer two feet of the concrete shell.

A wooden floor, shown in all designs since 1898, was, after some discussion, and in deference to a wish by Mr. Thompson, left out. Sir Whately Eliot also thought it might prove troublesome when jacking up large plates, and he was not familiar with the wooden floors at Tilbury and Nova Scotia, which were said to have proved so satisfactory and from which it had been copied ; he considered, moreover, that in a climate like this the question of a wet floor was not of the same moment as in Nova Scotia.

The section, pumps, caissons, workshops, cranes, keelblocks, windlasses, bollards, mooring rings, and all other details met with his approval, and he expressed himself as highly pleased with Mr. Thompson's proposal to use a diving bell somewhat similar to that used by Mr. Stoney in Dublin, its method of employ being to set up the frames for the concrete on barges, pick one up and lower it into position and then lower the bell over it. When the first frame had been filled the bell would be raised sufficiently to clear the frame moved over the next one already lowered in position

and let down, the operation being repeated continuously. After the concrete had had time to set divers would open the frames, which would then be removed by a crane and put together ready for another block, the bell returning over the blocks already laid to fill in the joints, which operation would be conducted by lowering a sort of canvas band filled with concrete, as it descended between two blocks until the joint was full to the top, and then dropping the ends of the band and feeding concrete on to the fresh concrete continuously so that the first deposited flowed out, only the outer surface ever coming in contact with the water, and that always the same surface.

The estimate for the first instalment of the dock at Rous Head—length 592 ft. on floor, 610 ft. at coping—was £285,000, the entrance width being 100 ft. and the depth on the sill at L.W.M. 34 ft.; depth on keel blocks, 32 ft.; length when complete, 910 ft. between caissions.

Sir Whately Eliot gave the following replies to questions asked by the late Mr. Price, then Minister for Works:—

> "Taking everything into consideration, I consider Rous Head the best site; if the railway were on the south side I should not consider any site more suitable."
>
> "I would have selected this site if the river were open."

As already hinted, every conceivable method had been considered for building this dock—from churning out wall trenches to driving sheet piling or churning out a puddle trench to surround the whole area, and this method was very tempting, but the author did not think the underlying clay beds sufficiently thick or continuous to warrant the risk, believing that water would pour up from the bottom in such quantities that no concrete could be laid in the dry. Consequently, as already stated, it had been determined to build the outer concrete shell either with the aid of a flume or diving bell. That Sir Whately Eliot was thoroughly in accord with this decision is proved by the following extracts from his report:—

". . . . This rock, however, is of such a porous nature that it cannot be relied on for excluding water, especially on the harbor side, where it has been excavated to form a deep channel, so that when the excavation for the dock is taken out there will be left a wall of rock very porous in nature, and less than 200 ft. wide. Water also would certainly percolate through the rock at the bottom in such quantities as to render its reduction by pumping almost if not quite impracticable. . . .

"Under these circumstances any attempt to exclude water from the site by a cofferdam in the usual manner would probably end in failure, and whether it succeeded or not would be very costly; other means, therefore, must be adopted for the construction, as explained hereafter . . .

". . . . . The construction of the dock is quite practicable ; it is a work, however, which will present difficulties, and will require the greatest possible care in construction—but the means proposed to be adopted, and explained later on, will considerably lessen the difficulties and minimise the risk of constructing a work of this nature under water. . . . .

" I recommend that as the nature of the ground does not admit of excluding water from the site by means of a cofferdam, the sand and rock be first removed by dredging. . . . . The bottom should be then levelled and prepared for the deposit of concrete by means of a diving bell provided with a double shaft and fitted with air locks by which men and such material as concrete, etc., may obtain access to the interior of the bell without removing it from its position.

Someone having proposed to return to the method of depositing the concrete by means of a skip in lieu of per bell, the author, who did not think high-class concrete could be laid by skip, wrote to consult Sir Whately Eliot on August 2nd, 1909, as to an alternative means. The following extract from the letter explains itself :—

" I have suggested as an alternative cutting blocks of granite by plug and feather as large as our cranes would allow, but certainly not under 6 ft. x 4 ft. x 3 ft. and probably double that size, say, 7 ft. 5 in. x 5 ft. x 4 ft., laying them on a bed of 2 to 1 cement mortar about 6 in. apart and then forcing 2 to 1 cement mortar through a pipe to fill up the spaces between them. By thus covering the bottom with a layer whose long axis was parallel to that of the dock, each row breaking joint with the next and covering it with a second layer, breaking joint everywhere with the lower, the stones sitting on their narrow side in both layers, the sides being built up with similar stones on the flat to above water level and all breaking joint, I think the dock would be pretty water-tight when pumped out for the purpose of finishing off the inside in the dry.

" The inland granite cuts beautifully: it is not all cracked and fissured nor flinty like that in the Darling Ranges. When walling in big rocks, *i.e.*, putting a gutter round them to collect water for railway purposes, I used to cut slabs about 60 to 70 ft. long by about 4 ft. 6 in. wide and 12 to 18 in. thick for about 30s., the cutting of them into lengths that could be handled being an extra, depending on the distance to be transported ; if used where cut, I have turned up as much as 22 lin. ft. in one piece. The principal reason for the excessive cheapness being that the great variations in temperature cause a shell to flake off the rock, which can expand and contract above the mass. For large quantities of stone one would have to rely on the solid rock."

The reply to this must have been mislaid, there being no sign of it among the author's papers.

The means of cementing the stones together is only touched upon in the above letter, but the method would have been after a few rows of stones had been laid to block the outer ends of all joints by sand bags or other approved means, lower the grouting pipe to the bottom, fill it with 2 to 1 cement mortar, then raise the pipe two or three inches and force in mortar until it had risen up level with the top of the stones, and then withdraw the pipe and renew the process again and again ; or fill the joints with broken stone and force grout instead of mortar, as described above.

The following information, together with plan of sections of dock and pump well, was supplied to pump makers to allow them to tender for pumps, the design being left to maker.

Capacity of Pumps.

The dock when completed will be about 910 ft. long (between caissons) and will contain, when filled to H.W.M., about 25,000,000 gallons of water.

The pumping plant, which it is proposed to place in a well be cope level, must be capable of discharging the above quantity in 4 hours.

The floor level of the dock on the centre line will be 36 ft. below low-water mark, and at the sides 6 in. lower.

The section proposed for immediate construction will be 560 ft long between caissons, and capable of being divided into 2 compartments, 210 ft. and 330 ft. long respectively, by an intermediate caisson.

The capacity of section to be built immediately, when filled to H.W.M., will be about 16,500,000 gallons. The pumps shall be designed as three equal and similar units, so that if only two such were ordered now, they would be capable together of pumping the present section in 4 hours, and that the addition of one other such unit when the whole dock should be completed would render the complete plant capable of pumping the full dock (capacity 25,000,000 gallons) in 4 hours.

A smaller drainage pump to be also supplied.

Discussion.

Mr. J. W. Henderson said all that Mr. Snields has quoted *re* tonnage passing through a port to necessitate a dock for repairing ships' hulls, etc., is true ; in fact, Fremantle is situated in a geographical position

that makes the situation more acute. The first site proposed is shown on the model at the Museum, and when attempts were made to put down a shaft to a depth of about 14 ft. was attained with timbering. When iron cylinders were used, a depth of 27 ft. with Pulsometer pumps was attained. Mr. Napier Bell was my informant about this, as I was his mechanical assistant at the time, and advised him to put the shaft down. The borings for the Rous Head site showed a nasty foundation, and late developments have shown that it was unwise to attempt a dry dock there. I pointed this out to Mr. Napier Bell, and as far as I recollect his reply was "It is better than a quick-sand." With reference to floating docks, Mr. Shields is in error. In 1890 and 1891 I was in Fremantle and foresaw the difficulties, and on return to England obtained information and submitted it to the Public Works Department. I am still in favor of a floating dock for Fremantle. I have seen them, been on them, and while their upkeep is more and their life shorter, they are to be preferred to a dock that has not eventuated, and accidents happen to even the best graving docks that have been constructed.

MR. J. F. RAMSBOTHAM did not consider that tonnage has any connection with the number of graving docks required. One might say that the Suez Canal ought to be composed of graving docks. And another point, graving docks are usually in places where there are the established industries of ship-building and also where repairs are carried on—generally at terminal ports. A letter from Mr. Napier Bell to Mr. O'Connor, suggesting putting a bank of clay round the whole site, say 7 or 8 feet in depth, to keep the surface water on the top of the reef away and taking the walls out in trenches all round, and then taking the floor out in sections, also in trenches, and I am bound to say, in my opinion, if that had been done you would have had a graving dock at Fremantle. In the work I have been engaged on we have had the water right up against us—a head of 54 feet of it—and I had got lower than Mr. Napier Bell. It was a much smaller dock at that time and the depth he (Mr. Napier Bell) was going to found on was 37 feet below low water mark. In regard to the suggested dredger scheme: if we are going to dredge the body of the dock out and then concrete under water before starting, one must have absolutely no doubt about the bottom. The author suggests putting clay on the bottom and ramming it. Personally, I have done a good deal of work with clay, and I know this, that if you ram clay you turn it into mud—the portions of sand, etc., in it become disintegrated and it becomes mud. Then, apparently, that having been done, concreting was going to be started with a flume. When your concrete goes into mud, the specific gravity of the concrete is greater than mud and the mud will come up and mix with the concrete and you will have an unsatisfactory mixture. Again, looking at pressures, the safe intensity of pressure on natural foundations has been determined as follows:—

(1) On hard rock, 9 to 10 tons per square foot;

(2) On soft rock and hard clay, 2 to 3 tons per square foot;

(3) On sand and gravel, $1\frac{1}{2}$ to 2 tons per square foot;

(4) On compact earth, 1 to $1\frac{1}{2}$ tons per square foot;

(5) On soft uncertain ground, $\frac{1}{2}$ ton per square foot.

Several engineering features manifested themselves during the construction of the Brocklebank Graving Dock, Liverpool, which I carried out under my late chief, Mr. Anthony G. Lyster. In three different places it was necessary to excavate 80 ft. in order to get a safe foundation, needless to say at considerable expense; but in work of this character no gratuitous risks must be taken—if they are taken and disaster follows the amount involved in getting a safe foundation is very small in comparison with the amount entailed by the disaster. To my mind there are three points an engineer must consider:—

(1) Can the work be done?

(2) What will it cost?

(3) How long will it take?

Then, further, in constructing a graving dock there are two cardinal points. In almost all excavations water is encountered, and a decision must be arrived at as to whether it is going to be possible to allow such water to weep away in relief or necessary to block it out, on account of there being too much water for the drainage pump. In the event of the latter concrete *en masse* is necessary, or a floor fortified with steel capable of withstanding the hydrostatic pressure from below. It was my intention (without any option) to have done this with the graving dock at Rous Head. In the case of the Belfast graving dock, which I saw when it was under construction, the floor was, I believe, 20 feet thick and a 5-ring blue brick arch in the concrete in addition, which was carried up the back of the walls. The issues are quite clear and it is advisable to realise them before starting. The next consideration is, what pressure will arise when a steamer is on the keel blocks? An Atlantic mail boat has a pressure of 80 tons to the running foot; with keel blocks at 30″ centres, this amounts to 200 tons per block, or, say, 175 tons for an ordinary type of mail boat. In the case of a damaged keel which has taken up an arch formation for considerably over 100 feet, these pressures may be considerably increased and all possible contingencies must be considered. In the case of the pressures on the toe of your wall, for a wall similar to the Fremantle graving dock, a pressure of 5 tons to the square foot arises, and unless the ground is suitable unquestionably trouble may be expected. For a wet dock 4.4 tons per square foot arises and the possibility of the wall sliding must not be forgotten. Then the author goes on and talks about putting in a shell. When you are putting in a shell to withstand the

ultimate pressures, the dock on being unwatered for the first time gets the ultimate pressure straight away. A shell is very little use unless it is so constructed as to be able to withstand the ultimate pressures. I am not quite clear about the method adopted at Glasgow, and perhaps the author would tell us how they did proceed, at the same time giving us the depth of water on the sill. And then going on further, I see a wooden floor was discussed. I have seen a drawing of it—an arch somewhere about 6 feet thick made under water with joists on it and then a 2″ floor. There was one other point I saw about dredging out and making concrete blocks, then putting a skim of concrete on the bottom and placing on it the concrete blocks. My remarks about pressures apply in the same extent to that method—a doubtful method, very doubtful; it is hard to build a big concrete arch in the dry, to build such under 50 ft. of water borders on the absurd.

Mr. A. J. Hillman said: In reference to the shipping tonnage at the various ports referred to by the author, I think it would be advisable to render that a little more clear by stating whether the tonnage is tons of shipping or the tonnage of shipping inwards and outwards combined, as is shown in the case of Fremantle, and whether it is gross tonnage or nett tonnage. The figures for Fremantle are up to date in that matter of 4½ millions, whereas the figures for the other ports are evidently four years old. I think four years ago Fremantle was about 2½ millions. In joining new work on to work which is two or three days old it has always been my practice to scabble the existing work and coat it thoroughly before bringing fresh work on it, and I think that is the only method by which a continuous bond and a continuous body of concrete can be formed, and the only way to prevent vertical seams or even horizontal ones in a work That is my method, and which has always been my practice in the dry, but to carry out similar methods under 40 or 50 feet of water is impracticable, and I think that a dock floor would be exceedingly porous when it came to be under water for the first time. A dock site cannot be dredged like cutting cheese with a knife, and a very uneven bottom would be the initial result if that is covered by the next proposal—an artificial bottom of clay, etc. What method of ramming would the author propose by which to ram clay dredged from Perth water 30 feet under water? I picture up a "pug" of about the consistency of pea-soup in which any system of ramming would generate into; any system of ramming is to my mind absolutely impracticable.

Mr. J. A. Ridgway said: Nobody will deny that this paper is an extremely interesting one. There are many matters of more than passing interest. In Whittaker's Almanack for 1910, the shipping tonnage of 1908 is given, which is exactly four years ago. This tonnage evidently refers to nett tonnage, which is the usual method of measuring tonnage. The tonnage is divided up into tonnage entered and cleared. According

to Whittaker, in 1908, Southampton, instead of having a tonnage of 3,800,000, as stated in the paper, had a total tonnage of 7,921,000 tons. On the same basis, Newport, instead of 2,700,000 tons, had 3,894,000 tons, and so on. Glasgow, instead of 4,300,000 tons, 5,000,000; Cardiff, instead of 13,200,000 tons, nearly 15,000,000; and Newcastle, including North and South Shields, instead of 9,000,000, 12,489,000 tons. For Melbourne and Sydney the tonnages are given for 1907 and they are respectively 743,246 tons and 1,884,700 tons, instead of 6,500,000 tons and 5,900,000 tons. As regards Fremantle, the author gives the tonnage for 1912, and I have it only here for 1907, but it then approximately amounted to about 1,000,000 tons. That, undoubtedly, is nett tonnage, whereas the author's figures may be in reference to gross tonnage, and I shall be glad if he will enlighten me. Of course, if the tonnage I have given for Melbourne is correct it all the more points to the necessity of having a dock here in Fremantle, when Melbourne, as the author says, has three docks and five slipways. The statement the author makes as regards foreign ports not having so many docks as British is very interesting, and I should be glad if the author could give me the name of the port to which he refers just below as having a 50 feet rise and fall of tide and having only one gridiron. The author states that the idea was to design a dock which would be satisfactory for discharging cargo and cleaning the ship's bottom at the same time. The majority of shipowners are, I think, always against putting their ships into dock in a loaded condition, for it is clearly advisable to empty your ship so as to do away with any tendency to strain. When men are working underneath it is hardly a good proposition to discharge cargo at the same time. In Liverpool I can only call to mind one ship which discharged cargo in the graving dock. The author's reference to floating docks is all too short. It would be interesting if he would briefly give reasons as to why the floating dock proposition was apparently shelved, and in addition would he state his views as to the respective merits of a dry dock over a floating dock, or *vice versa*.

Mr. W. Leslie said there are a few points, some of which have been mentioned, that in my opinion ought to be made clear when the paper is revised. Several references have been made to the tonnage and it is not clear whether the tonnage is annual or not. I agree with Mr. Ramsbotham, it depends entirely on the status of the port as to the number of docks required. As pointed out, ship owners are very loth to put the ships into dock when they are loaded, and in every occasion where it has been done it has caused considerable extra expense and also in the insurance. A port of call like Fremantle is not to be treated in the same manner as a terminal port, or in the same way as a port where there are facilities given for repairs being carried out to ships when they call at the port. The author refers to the difficulty to docking a ship when the ship is at right-angles to the stream, but I think exaggerates it. We

know that a great many docks are placed in rivers at home where there is probably 10 or 15 feet rise and fall, and taking one ship out and putting one in on the top of a tide. There is a great deal more work done in more current than we are ever likely to get in the estuary of the Swan; this difficulty may be got over by tugs. Timber docks were, I think, first built in America, and they were known as the Simpson docks. I think there has never been an instance yet of a timber dock floating, the reason being that the sloping sides—they were very wide batter at the bottom—were all very deeply piled and the fastenings made to the piles so that really the dock was well anchored down. There was one burnt, I believe, but I think, although it was constructed of timber, we have not had an example of a Simpson dock floating yet. Of course, repairs to the timber docks are very much higher than the other docks, to which the cheap construction lends itself. There is one thing that the paper does make clear, and that is the strata at Fremantle appears to be perfectly well understood in Mr. O'Connor's time. I think Mr. O'Connor, from the information which he had before him, was remarkably correct in regard to the strata at Fremantle; a good deal of information in regard to it has been obtained since Mr. O'Connor's time, and, of course, it is all the more credit to him to be able to foresee that. The author must have had a good deal of trouble in regard to the way he proposed to put up a working stage and deposit his concrete down there. It would have been of value to have had more particulars as to that, the moving of that flume and the opening the door—the moving of the flume along the bottom. It does not appear to me, however, to be practicable. The history of the No. 4 graving dock in the Brookland Navy Yard seems something like Fremantle. In the first instance a contract was let for the construction of a dock 563 feet long and about 100 feet wide. After fifteen months' work the contractor decided not to proceed further. A little later the Government again called for tenders for the dock, 620 feet long. A company got it and decided they would adopt a method somewhat similar to what was employed at Fremantle. That was the two lines of steel sheet piling, and endeavored to get the site dry in that way. They worked on it also fifteen months and failed, and for a second time the work was abandoned. The Government found it necessary to have a dock. Ships were calling for dock accommodation, and their own cruisers made it necessary to lengthen the dock again. Tenders were called again, and the length increased to 723 feet and the width I think 100 or 120 feet, but it was a success the third time. The contractor took one of the ways of which the author has not taken into account. That is, he sunk a series of caissons right round the outside of his dock—they were a little distance apart; where they were joined he left a half-moon so that the concrete could afterwards be filled in between each of the casoons right round. The Government Engineer went into the matter with the contractor in regard to putting in a reinforced bottom

instead of the ordinary concrete bottom. It saved some 10 or 15 feet in the deptn of the concrete in the bottom, but the difficulty there was that the strata was quicksand and loose sand, gravel and boulders down to 110 feet below the surface, so that each of these casoons sank down to solid rock 110 feet and the work was at length completed. There are one or two things in the proposed method of construction of the dock that the author sets out that rather puzzle me. One of them I refer particularly to—a suggestion which he made to Sir Whately Eliot, dated 2nd August. He refers to the adoption of a cut granite bottom. I quarried a good deal of these blocks in the hills, and I think one cannot go very far into that before it becomes very expensive. It is quite true they are lying in beds 12 and 18 inches and up to 3 feet thick, but when you proceed to get a large quantity of stone from anything you soon get into the solid granite, and then it becomes expensive—especially with our high cost of labor. The author says he would lay them in the bottom of the dock. I take it on a bed of cement and grout them in between, but what troubles me is how it is proposed to get the mortar down there, and I thought if one could get the stones down into the bottom for a foundation that they could get the concrete in all right.

Mr. Shields, in reply, said Mr. Henderson is quite correct in referring to the difficulties in sinking that shaft in Mr. Napier Bell's time, and there was also the same difficulty in sinking the shaft above the bridge. The water was pumped out and as the water was pumped out the sand rose in the shaft and they were not getting any deeper. If the water had been left in the shaft and an ordinary sand pump used it could have been sunk to any depth required without any trouble. As to the information on the floating dock that Mr. Henderson mentions, they did not act in conjunction—they both acted independently. There is a great deal about floating docks. Mr. Henderson also says that a floating dock would have been better than a graving dock. It is not a substitute—it has not got the stability. The stability of the ship has to be taken into account when you put a ship on the floating dock; and it has been said there have been accidents in graving docks, but there also have been accidents in floating docks. There have been accidents—where a ship launched herself off a floating dock, and the Havana floating dock broke in two. Coming to Mr. Ramsbotham's remarks: The tonnage has no connection with graving docks. Of course, there is a certain amount of reason in that, and where a port receives a large amount of shipping it ought to have graving docks in comparison with that shipping. In England, where a ship can go to an adjoining port a few miles away, it is not so important as here, where we are 2,000 miles from one. A ship coming all that distance is liable to accident. Mr. Ramsbotham said I was inaccurate in saying Mr. Dillon Bell proposed the first wooden dock at Rous Head, instead of Arthur's Head. I do not think I was. Mr. Dillon Bell proposed one for each side on two consecutive days. With reference

to the few notes in Mr. Napier Bell's letter read out by Mr. Ramsbotham, he refers first to the site at Rous Head and then to the site below the bridge, or conversely, but I thought it was quite clear from his letter which he referred to. In one he refers to the porous rock, the limestone rock interbedded with limestone rock and sand. In the other he refers to nothing but sand. And you would have to put sheet piling down, and if you went to lower the water 10 feet the sand would come up. There is no doubt there would be great difficulty. My idea is not to lower the water in either case—there was a shell of concrete, and the reason for that is that those who have had experience of this rock, say it would be exactly the same at the bridges. The rock at Arthur's Head and the rock above the bridges is not one bit better than the rock at Rous Head or Rocky Bay. It is all as porous as a sponge. Mr. Napier Bell thought there was hard limestone at the bottom, as you see in the papers; Mr. O'Connor disagreed with that. Mr. O'Connor maintained that the rock was absolutely porous. The next item is the rammed clay becoming mud and rising and becoming mixed with the concrete. I do not know whether Mr. Ramsbotham referred to the mud in Perth Water and clay. There is an outcrop of clay in Pier Street, and also in some Government land at the back of the Technical School. It appears to be a very tough clay and it has water running on it. If it was found to run it would have to be replaced by some better class of clay. A good deal was dredged up in Perth Water and it came out of the water perfectly tough. He referred to the weight on foundations—3 tons on clay and 2½ tons on coral in the United States. I do not think we can put that much weight on the bottom. If you take a 50 feet column of concrete, what would it weigh? I should say, allowing about 16 feet to the ton, it would go a little over 3 tons for the total column from top to bottom, and against that you would have the upward thrust of the water, which would relieve it by fully a third. There would be no sliding of the toe, because the invert bottom would prevent the toe sliding in. You would have the higher ground inside and the clay and the mud and you have to allow for all the water above water level. In a wet dock you have nothing to prevent your toe sliding out—in a graving dock you have the whole of the floor which prevents the bottom sliding across; it has an equal thrust on the other side of the wall. A warship is actually heavier than a ship like the "Lusitania," because she has a shorter level of keel. When the ship comes on the floor, as a matter of fact if the dock were not held down by friction it would float it. When the water was pumped out the dock would float, ship and all. So that it only comes to a matter of distributing the weight of the ship from the keel blocks over the floor. We had steel rails laid in the concrete—that was the actual proposal. I think the concrete itself would have taken it up—it would have spread the pressure. There are two ways of making the shell. If you laid a shell of concrete to be finished in the dry you must either make that shell of

concrete sufficiently thick to resist the water pressure and flotation if it is not held down, or else you must load it. In the case of the Glasgow dock they made quite a thin shell but they loaded it up with spalls or sand inside, and then they excavated in those spalls a narrow trench, that only left a narrow space of floor—I think it was 10 feet. If you take out a little strip as wide as a table right across the dock, a comparatively small thickness of concrete acting as a hidden arch will keep the pressure down, and you could make that piece tight, and, having made that piece tight, make an advance and make the next strip tight, the pressure on this new concrete keeping that down till you get the whole of it in. Mr. Ramsbotham referred to Mr. Rowland's method of laying concrete blocks under water. Of course, laying these under water presented difficulty, as any work under water does. I referred to a dock that was proposed to be put across the South Mole. I explained exactly—I mentioned the price for it. The reason for the excessively cheap price was that we had an offer at that time of a stack of slag from the smelter which I think the Government analyst reported on very favorably for concrete. The proposal was to make long blocks and grout them afterwards. It is exceedingly difficult and the trouble really is to get some feasible method of laying the concrete under water. It has been shown in many cases that the vertical joints can be grouted. I dare say a good many are familiar with the work that Canniple (?) did on the Guernsey structure—he grouted those through a pipe and made good concrete. We tried the same method at Fremantle with great success. We made some very nice blocks and grouted in different ways. You cannot have horizontal joints if you are grouting under water, but you can have them on the slope. Mr. Hillman referred to the table of tonnage at the ports. That was taken from a public file—I think it is from Mr. Palmer's report. It is on one of the public files; some of the men of our Department could tell you which, and at the time, as well as I remember, I compared that with the Fremantle Harbor Trust's report. In reference to the method of ramming with clay under water, the intention was to run it through the flume the same as the concrete. Personally, I think you could ram it if you got the right clay with a flat ram. You would have to force it through the flume. Mr. Leslie mentioned that a wooden dock was never known to float. I consider that they are too porous to float.

RECENT EXAMPLES OF LIGHTHOUSE CONSTRUCTION ON THE WEST AUSTRALIAN COAST.*

(By G. E. Farrar.)

General.

In 1906 the necessity for additional navigation lights around the Western Australian coast north of Geraldton was brought under the notice of the Government of the day by the various shipping companies trading between Fremantle, the North-West ports and Singapore. The increasing trade with the North-West and Singapore and the necessity of providing further protection to shipping and assistance to navigation by the erection of further lighthouses, etc., along the coast was generally acknowledged, and with the object of deciding the positions for such further lighthouses the Government appointed an advisory Board, comprising Captains Laurie, Arundel and Irvine, to collect evidence and submit a report with recommendations regarding the four most important lights calling for early erection. The evidence of a number of ship-masters having practical knowledge of the coast, and others interested in shipping, was taken, and in March, 1907, the Board presented their report, and, acting upon the consensus of opinion as deduced by the evidence taken, the Board recommended the erection of lighthouses at the following points, viz.: Cape Inscription, Point Cloates, Bedout Island, and Cape Leveque. The necessary surveys were at once put in hand and the preparation of plans, etc., proceeded with. Subsequently, owing to the loss of the s.s. "Mildura" on North-West Cape, the Board recommended, and the Government decided to erect, a light on Vlaming Head, a promontory to the south-west of North-West Cape.

Cape Inscription.

A bold headland at the northern end of Dirk Hartog Island, at entrance to Shark's Bay. The tower is erected near the spot where the Dutch navigator Dirk Hartog landed in 1616, and in a fissure of the limestone rock erected a post carrying a tin plate commemorating the event, hence the name Cape Inscription. This interesting memento was seen in 1801 and 1803 by Captain Hamelin and Captain Baudin, respectively, but when King, an English navigator, visited the spot in January, 1822, the plate had disappeared.

King erected a post on the spot bearing the inscription, "King 1822," in letters formed by clout-headed nails driven into the post. This post, etc., was in an excellent state of preservation, the original position was carefully fixed, the post removed, and subsequently placed in the Perth

*For figures and plans see end of book.

Museum. This course was adopted by the author, as owing to the scarcity of fuel it was almost certain this interesting relic would speedily have found its way beneath the homely billy.

The principal difficulties encountered in connection with the carrying out of this and other works enumerated were those of communication, transport, and landing of materials and the supply of water for use of man and beast in the execution of the work.

As regards Cape Inscription, the only available landing place within reasonable proximity to the site is distant one and a quarter miles, on a shelving sandy beach ; a heavy sea prevails here during the prevalence of northerly and easterly winds, there is also at nearly all times a very heavy undertow, which made the preliminary landing of materials extremely difficult and dangerous, and, I regret to say, a fatal accident occurred here in the early stage of the work. These difficulties were, however, lessened on completion of the jetty and inclined tramway shown (Fig. 1). The ruling grade of the tramway is about 1 in 3. The haulage was effected by horse power operating a specially designed winch on the summit of the cliff, and although the operation was somewhat slow, many hundreds of tons of materials were thus transported without accident. The transport of water was another difficulty, the source being a well distant from the work five miles, and owing to the sandy nature of the country trundling hogsheads were found more expeditious and less trying to horses than drays. Fig. 2 shows water in transit in the manner described.

THE TOWER, situated in Lat. 25° 29′ 30″ S., Long. 112° 58′ E., is built in non-reinforced cement concrete and is thirty-four feet in height to level of gallery floor, and eighteen feet external diameter at the base. In this is installed a third-order flashing light making one complete revolution in thirty seconds, giving four flashes of five seconds' duration, and four periods of darkness of two and one-half seconds' duration. The illuminated sector is 360°. Height of focal plane above high water, 127 feet ; range of visibility, 12 miles from bridge of an ordinary steamer. The total height of tower from base to lantern vane is 49 feet. The clockwork actuating the occulting screen was designed and constructed departmentally and is working admiralby. The lamp is a 50 mm. incandescent vapour type comprising three burners. Near the tower has been erected a flagstaff 80 feet in height for signalling purposes. (Fig. 3 is a general view of the tower, quarters, etc. Fig. 4 shows the tower in course of erection. Fig. 5, the completed tower.)

QUARTERS for two lightkeepers all under one roof have been provided. The walls are of cement concrete with iron roof. The accommodation comprises two living rooms, four bedrooms, two kitchens, two bathrooms, two pantries, two storerooms, etc. ; a spacious verandah is provided.

An underground tank of cement concrete of a capacity of 20,000 gallons for conservation of rain water has been provided; also oil store, wash-house, stabling and usual offices.

THE JETTY is 232 feet in length, with berthing accommodation for vessels of 10-feet draught, connected with the quarters, etc., by a 2-feet gauge tramway. An area of about 600 acres in extent, enclosed with sheep-proof fencing, has been provided.

COST, ETC.—The work was carried out departmentally throughout and was completed in February, 1910, and on 1st March of same year the light was first exhibited and the work handed over to the Harbour and Lights Department. The total cost of the work was £8,228.

POINT CLOATES.

The tower is erected on Cloates Hill, 138 feet above sea level, in Lat. 22° 42′ S., Long. 113° 42′ E., about 200 miles north of Cape Inscription. Owing to excellent sandstone being available, the tower and quarters are of masonry, in colour a pleasant warm brown; the stone, however, proved costly to work on account of its hardness.

THE TOWER (Fig. 6) is 47 feet 1 inch in height from base to level of gallery floor, and 19 feet 8 inches in diameter at the base. In this is installed a second-order dioptric flashing light by Chance Bros., Ltd., of Birmingham, comprising a three-sided optic, flashes $\frac{1}{3}$ of a second duration, eclipse $4\frac{2}{3}$ second; the height of focal plane above high water is 190.4 feet; range of visibility, 15 miles; illuminated sector, 200°; the height of tower from base to vane of lantern is 73 feet 6 inches. The lamp is an 85 mm. Chance incandescent vapour type of 300,000 candle-power. Near the tower a flagstaff 80 feet in height has been erected for signalling purposes. The internal iron work, such as floors, circular stairs, etc., were designed departmentally and constructed under contract in Perth.

QUARTERS (Fig. 7) for two lightkeepers, all under one roof, have been provided. The walls are of stone, roofed with iron, and comprise two living rooms, four bedrooms, two kitchens, two bathrooms, two store rooms, etc. A spacious verandah back and front has been provided, also oil store, stabling, wash-houses, etc.

TRAMWAY.—A 2-feet gauge tramway about $2\frac{1}{3}$ miles in length connects the quarters and oil store with the landing on the beach. An area of about 15 acres has been fenced in for use of the lightkeepers. The whole of the work was carried out departmentally at a total cost of £13,265.

VLAMING HEAD, NORTH-WEST CAPE.

A conspicuous headland some 60 miles northerly from Point Cloates, Lat. 21° 48′ S., Long. 114° 6′ 30″ E. This work is now in hand and it is hoped will be completed towards the close of the year. Much sickness

has prevailed amongst the workmen owing in a great measure to the bad quality of the water, and it has been found necessary to instal a condensing plant. The distance from the landing place (Fig. 8) to the site of the tower (Fig. 9) is 3¼ miles, and they are connected by a 2-feet gauge tramway.

TOWER.—The site of the tower is 200 feet above high-water mark. The tower is being constructed in cement concrete, and will be 30 feet in height from base to level of gallery floor and 17 feet 8 inches in diameter at the base. In this will be installed a second-order dioptric double flash light comprising optic of four panels making one revolution in 15 seconds, two flashes every 7½ seconds; duration of flash, 3-10th of a second; range of visibility, 18 miles. The lamp is an 85 mm. incandescent vapour burner, similar to Point Cloates, of 215,000 candle-power. An 80 feet flagstaff will be erected near the tower for signalling purposes.

QUARTERS for two lightkeepers are being provided, the accommodation being similar to Point Cloates. Detached quarters for a third lightkeeper have been requisitioned for by the Commonwealth authorities, and will be provided. The work is being carried out departmentally. All the internal ironwork of the tower, floors, stairs, etc., was made in Perth. It is proposed to fence in an area of 160 acres as a reserve of this work.

COST.—The total estimated cost of the work is about £17,300.

BEDOUT ISLAND.

Situated in the Indian Ocean in Lat. 19° 35′ S., Long. 119°, 6′ E., about 55 to 60 miles in a north-easterly direction from Port Hedland. It is a low-lying coralline island in the direct course of steamers making to or from Broome. The Board of enquiry considered this the most important light required on the North-West coast, but its isolated position, long extent of reefs and high tides rendered the establishment of an attended light a very difficult matter.

Preliminary experiments were conducted at Fremantle with an unattended dissolved acetylene light, for a period exceeding six months, and proved so eminently satisfactory that it was decided to instal an unattended light of six months' duration, and an order for the apparatus and steel tower was placed with Messrs. Chance Bros., Ltd., of Birmingham, and duly received and erected, and was placed in commission on 14th December, 1909.

THE TOWER (Fig. 10), which is of open braced steel, founded upon a massive concrete base, is 51 feet 1½ inches from ground level to lantern vane. The light is an occulting one of the fourth order, 2 seconds light, 8 seconds eclipse, dioptric lens, illuminated sectior 360°; height of focal plane above high water, 67.21 feet; range of visibility, 9½ miles. The

total cost of the work was £4,167. As this was the first long period unattended light erected in the State, and as the "Aga" apparatus may be new to some of my audience, I propose to describe same as briefly as possible further on.

Cape Leveque.

This light is situated at the entrance to King Sound, in Lat. 16° 23′ S. and Long. 122° 55′ E.

The Tower (Fig. 11) is of cast iron, designed departmentally and manufactured under contract by Mr. B. Makutz, of Perth, and is 28 feet 4 inches in height from ground to level of gallery floor, and 12 feet in diameter at the base, and is surmounted by a lantern containing a fourth-order triple flashing light making one complete revolution in 15 seconds, producing three flashes of about $\frac{1}{3}$ second duration in quick succession every 15 seconds. Height of focal plane above high water is 142.4 feet; range of visibility, 14 miles. Height of tower from base to lantern vane is 43 feet 6 inches. Fngle of illuminated sector, 215°. The lamp is a 55 mm. 3-burner "Chance" incandescent vapour type of about 25,000 candle-power.

Quarters (Fig. 12) for two lightkeepers, all under one roof, are provided. The question of the type of construction for these quarters was the subject of some deliberation. Stone was procurable but costly to quarry, and the site being situated in the tropics only some 16° south of the equator, and owing to the great heat prevailing here for the greater part of the year, it was considered inadvisable to construct the walls of either masonry or concrete, as these materials once thoroughly heated retain heat for a lengthened period, and dwellings become insufferable, especially at night, making restful sleep almost impossible. It was therefore ultimately decided to construct the dwellings of timber framing covered externally with corrugated galvanised iron laid horizontally and painted white; internally the studding is covered with "Keylock" corrugated interlocking steel lathing and plastered. Although by this method of construction the buildings become very hot huring the daytime, they cool rapidly after sundown, rendering the premises bearable at night. The roof is covered with $\frac{3}{4}$ inch sarking and on this is laid asbestos coated malthoid. The building is surrounded with a verandah 8 feet in width. The accommodation is similar to that for other quarters already described. A corrugated galvanised iron tank of 20,000 gallons capacity is provided. A reserve of about 490 acres has been fenced in.

The total cost of the work was £9,219. Fig. 13 shows material being landed on the Beach.

This completes the description of the work appertaining to those originally recommended by the Advisory Board.

The following additional lights were subsequently recommended and approved and are now in course of erection :—

Black Peak.—On the west coast, about midway between Fremantle and Geraldton. The apparatus is already ordered for this light and will be practically a replica of that at Cape Leveque. The tower will be of concrete ; the height from ground level to focal plane will be about 95 feet ; range of visibility, 15 miles. Detached quarters for two light-keepers will be provided and communication by telephone to Dandaragan (the nearest telegraph station), a distance of about 45 miles, will be established, thence messages can be transmitted to Fremantle and Perth, etc.

Three unattended acetylene "Aga" lights are under order for Mary Ann Passage, to be erected on Anchor, Airlie and North Sandy Islands, respectively, each having a range of visibility of 15 miles ; also similar lights are to be erected at Cape Bossut, with a range of visibility of 14 miles. and Point Torment, Derby, with a range of visibility of 12 miles. All towers for above are to be of the open steel lattice braced type founded upon concrete, and have been designed departmentally.

Unattended beacon lights have also been established at King Point, Albany, and at the head of the Mole, Bunbury. Both these lights have been fitted with a sun valve, an automatic device which extinguishes the main light during the day, leaving only a small pilot light in service, and as daylight decreases so the apparatus turns on the main supply of gas.

All the five new unattended lights previously referred to will be fitted with this apparatus, and, at the risk of trespassing still further upon your patience, I propose to briefly describe the apparatus, dealing firstly with the lighting apparatus and then with the sun valve.

Purified dissolved acetylene is stored in steel cylinders, called accumulators, of varying dimensions, according to requirements. These accumulators are filled with what is known as the "Aga" porous substance, and it is of the greatest importance that this substance is so constituted that it does not change with time, thereby diminishing the guarantee of safety and utility. The "Aga" porous substance consists of a ceramic mass with a certain percentage of fibre of an elastic nature, usually asbestos ; this substance has stood the test of years and may be regarded as unchangeable and so immune are these accumulators from risk of explosion that they are carried by vessels as ordinary "'tween" deck cargo, and in order to ascertain the result of high temperature a charged vessel was bedded in a wood fire, in another a hole was melted through the steel casing—in both these instance the gas merely burnt away—there was no explosion ; in a third case to ascertain the result of shock an accumulator was fired at with a steel projectile, which passed completely through the vessel without causing an explosion. They are

generally charged to a pressure of from 10 to 17 atmospheres. The complete lighting apparatus is shown on Fig. 14, and comprises three sections, viz.: the governor, flasher and burner. These I will briefly describe in the order enumerated.

GOVERNOR.—The gas enters the apparatus through the pipe *A* and valve *B* at the same pressure as it leaves the accumulators, and raises the membrance *K*, which acts upon the lever *F* by means of the lifting eye *I*; the lever *F* is movable about two centres and is held against the stay *H* by means of the spring *G*, the valve *C* is then kept open owing to the pressure of the spiral spring *D*; When the pressure of the gas raises the membrance, the lever *F* is drawn upwards, the valve stem *E* pushes the valve disc towards the seat *B* and diminishes the gas inlet so that this will correspond to the gas outlet. The gas leaves the governor by the pipes *L* and *M*, one of these delivering a supply to the flasher and the other to the pilot light. From the above description it will be understood that the governor is really a reducing valve.

FLASHER.—The gas enters this portion of the apparatus through the pipes *A* and *B* and the valve seat *C*, and lifts the membrance *D* gradually, the spring *E* and *I* act on the lever *G* with the same power but in opposite directions; this lever *G* is magnetised and answers against the armature valve seat *H* in which the outlet for the gas is shut so long as *G* answers against *H*. When the membrance *D* is lifted by the gas pressure the spring *E* is drawn against the loop *F*, which is connected to the lever *G*, and this lever will during the time answer against *H* by reason of its magnetism, when the gas pressure is further increased it adds to the tension power of the spring *E*, and *G* is loosened from its seat *H*: at that moment the action of the magnetism between *G* and *H* becomes inoperative and the lever *G* is suddenly pulled away from *H*, the gas escapes through the opening in *H* and through the piping *K* and *L* to the burner, the lever *G* comes by its pulling away from *H* into contact with the valve seat *C* arranged above the lever G; in this valve seat *C* is, as already explained, the gas entrance to the apparatus, and this is then shut by the lever *G*. When the gas exhausts from the apparatus the same movements are made in reversed order. The play of the spring *E* in the loop *F* is diminished by screwing in the wedge *N* between the spring *E* and the loop *F* by means of the screw *M*, thus the quantity of gas required to draw up the lever *G* is diminished and this gas quantity answers to the light period, thus the length of the light period is adjusted by the screw *M*. The adjustment of the relation between the light period and the whole period (light period plus dark period) is made by using the screw *O*: by screwing in this the gas quantity which enters the apparatus per unity of time is diminished; as the gas pressure during the outrush of the gas to the burner is constant (suitable to a good flame) the relation between the light period and the whole period is diminished by turning in the screw *O*.

The Burner calls for little description. The stem carrying same is adjustable vertically by means of the set screws *X* so as to bring the centre of the flame to the local plane.

The Sun Valve is an automatic apparatus in which the radiating light of the sun is used to close the gas passage to the burner, which is kept open when the apparatus is not exposed to light. The action of the apparatus is founded on the well-known principle that a body with a surface that absorbs light will acquire a higher temperature, and thus expand more than a similar body with a surface that reflects the light when both are exposed to the same light. Fig. 15 illustrates the internal arrangement of the apparatus. *A* is a metallic bar with a light absorbing surface; three bars (*B*) are made of the same material and have the same co-efficient of expansion as *A*, but are placed inside tubes (*C*), which are carefully polished and gilded and are so rendered light reflecting. *A* is surrounded by a glass tube (*D*), which allows the radiating light to pass in but prevents the heat rays which emit from *A* to pass out; the bars (*B*) are also protected from the heat rays from *C* by means of glass tubes (*E*). These glass tubes also prevent the bars (*B*) from being cooled faster than *A* in darkness. The bar (*A*) acts upon the valve lever (*F*) so that when the apparatus is exposed to light and *A* gets a higher temperature than *B*, it expands more than *B* and presses *F* against the valve seat (*G*), thus shutting the gas passage; *A*, expanding still more, the spiral spring shown in the upper part of the apparatus will be compressed. When in darkness *A* valve will have the same temperature as *B*, thus contracting and allowing the valve lever (*F*) to be lifred from the seat (*G*) by the spring (*H*), thus opening the gas passage.

When the sun valve is exposed to sudden changes of temperature, by winds, rain, etc., the bars expand or contract in the same degree, thus without interfering with the gas passage. The gas inlet is through the pipe (*I*) and the outlet through *K*. The gas passage, or compartment, is carefully separated from the upper portion of the apparatus by means of the metallic membrance (*L*). By means of the screw (*M*) the sun valve can be adjusted so as to light the flame at such intensity of daylight as may be found desirable. After the point on top of the apparatus is unscrewed the screw (*M*) can be turned with a special key and the turned angle observed on the pointer (*O*) and the circular scale; when the screw is turned to the right the valve is closed; the axial movement of the screw (*N*) which acts upon *A* and thus upon the valve lever, is very small, because *N* is threaded in the screw (*M*) and the threads in and outside of *M* have very little difference in pitch. When the sun valve is submitted to tests it must always be remembered that it is the caloric effect of the light that acts upon the apparatus: thus in a pale light it will take a relatively long time (some minutes) before the valve will come into a position corresponding to the light. If the protecting hood is put

on the sun valve when exposed to strong sunlight it will take some minutes before the heated black bar (*A*) is cooled.

Messrs. Gardner, Waern & Co., the Australian representatives of the "Aga" light, have very courteously lent me their demonstration apparatus (working model), which I submit for your examination. I feel that you will appreciate, as I do sincerely, their kindness in affording us such an opportunity.

Discussion.

In reply to questions, the Author intimated that the makers do not divulge anything as to the nature of the metals used in the sun valve. Automatic lights have been extinguished by gales, as was the case during the cyclone last March, when the Bedout light was blown out, which is believed to have been caused by too much ventilation under the dome of the lantern. There is no means of automatic re-lighting. No trouble is caused by the jets carbonating. From 500 to 1,000 up to 1,500 candle-power, for a single flame, according to the different size of the lenses, are most frequently used. The gas used is compressed and varies from 10 to 17 atmospheres. It is absorbed in this "Aga" porous substance, as they call it. Ordinary acetylene gas, if it is compressed up to about two atmospheres, becomes explosive, but this does not. That is the beauty of this system—there is absolutely no fear of explosion.

INTERSTATE CONFERENCE ON THE ARTESIAN WATER SUPPLIES OF AUSTRALIA.

(By A. Gibb Maitland.)

On a previous occasion when addressing the Western Australian Institute of Engineers on the subject of the geological considerations affecting the artesian water supply of the State, it was pointed out that the United States Government appointed a commission consisting of geologists and engineers for the purpose of making an exhaustive scientific examination of the arid regions of the Interior, and the hope was expressed that some day such a body would be brought into existence locally.

In April last I was privileged to attend, as the representative of Western Australia, the Interstate Conference on the Artesian Water Supplies of Australia, which sat in Sydney.

The Conference was called together for the purpose of taking stock, as it were, of the artesian water supplies of the Commonwealth, and to ascertain how long they are likely to last, and if the valuable asset was not illimitable to devise some workable means where by properly developing the supplies to do so in such a way as will benefit not only the existing community, but succeeding generations.

This Conference was perhaps one of the most important gatherings which has yet been held in Australia. The representatives comprised four Hydraulic Engineers, representing New South Wales, Queensland and Victoria, respectively, together with the Government Geologists of New South Wales, South Australia and Western Australia, and an officer of the Public Works of New South Wales, who acted as Secretary.

Amongst the more important facts elicited during the course of the deliberations of the Conference were :—

(*a*) The very large portion of Australia occupied by artesian water areas and the extent to which the interests of several States are involved in regard to more than one of the known artesian basins ;

(*b*) The amount of work which has been officially done on the artesian basins of Australia, and the very variable degree of precision of the investigations carried out in the different States ;

(*c*) The very marked and serious diminution both in the flow and pressure of those artesian wells of which periodical measurements have been made under direct Government supervision ; and

(*d*) The very serious corrosion of bore casings, which up to the present time, however, seems confined to certain restricted though extensive areas of Australia.

After fully discussing the matter of the source, utilisation and conservation of the artesian water supplies of the Commonwealth, the Conerence recommended, *inter alia*, for the consideration of the respective Governments of Australia :—

(1) A uniform system of delineating the different artesian wate basins ;

(2) A hydrographic survey, with the view of arriving, so far as is possible, at an estimate of the water annually absorbed by the respective basins ;

(3) Legislation to prevent an unnecessary multiplication of bores ;

(4) Uniform legislation to ensure the effective control by the States of all existing and future bores within all artesian basins ;

(5) No new irrigation enterprises which depend for their supplies of water upon artesian wells being inaugurated until certain investigations recommended by the conference have been carried out ;

(6) A uniform system of casing all artesian wells ;

(7) Investigations into the composition and structure of the metals of which bore casings are made, and into the efficiency of coatings or linings in such casings, in so far as their powers of resisting corrosion are concerned ;

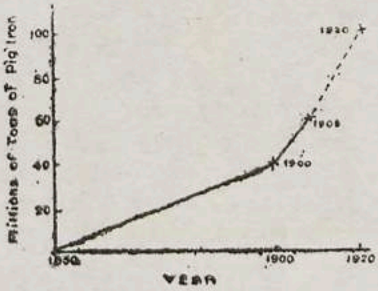
(8) The formation of a permanent interstate board for the discussion, correlation and recording data in regard to the artesian basins of the Commonwealth ;

(9) The cost of any special investigations recommended by the Conference being borne in equitable proportions by the respective States.

It may perhaps be of interest to note that this conference virtually forms a part of that great modern scientific movement of the Conservation of Natural Resources, which is slowly but surely making itself felt throughout the whole civilised world.

Year.				Pig Iron Produced. (Millions of Tons.)
1800	...	...	...	0·5
1850	...	...	...	4
1900	...	...	...	40
1904	...	...	...	46
1909	...	...	...	60

These data are shown graphically in Fig. 1.



Curve Illustrating the Annual Productions of Pig Iron Since 1800.

Illustration 1.

Acid : hydrochloric HCl $= \overset{+}{H} + \overset{-}{Cl}$

Base : sodium hydroxide NaOH $= \overset{+}{Na} + \overset{-}{OH}$

Salt : sodium chloride NaCl $= \overset{+}{Na} + \overset{-}{Cl}$

or to give more complete examples :

Acid : sulphuric $H_2\ SO_4$ $= \overset{+}{H} \cdot \overset{+}{H} + \overset{=}{SO_4}$

Base: calcic hydroxide $Ca(OH)_2$ $= \overset{++}{Ca} + \overset{-}{OH} \cdot \overset{-}{OH}$

Salt : calcic sulphate $CaSO_4$ $= \overset{++}{Ca} + \overset{--}{SO_4}$

Illustration 2.

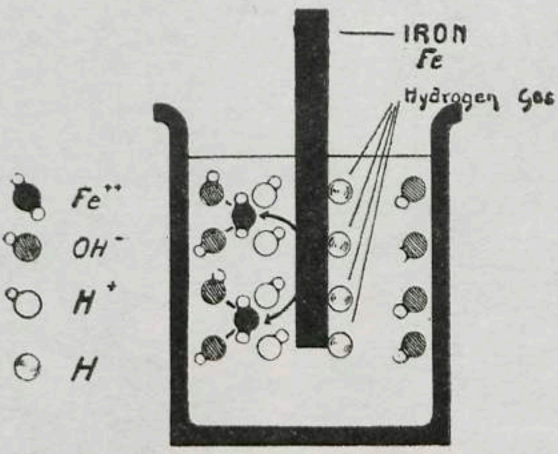


Illustration 3.

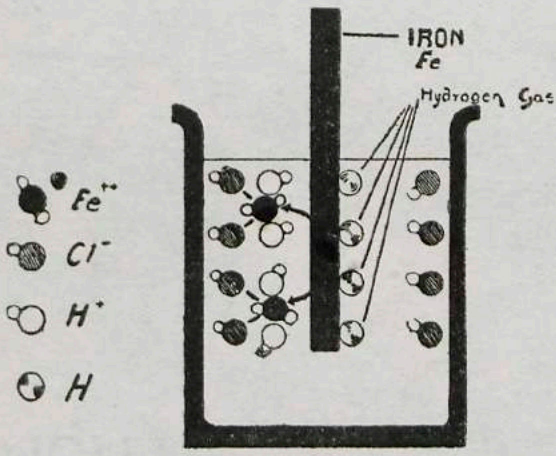
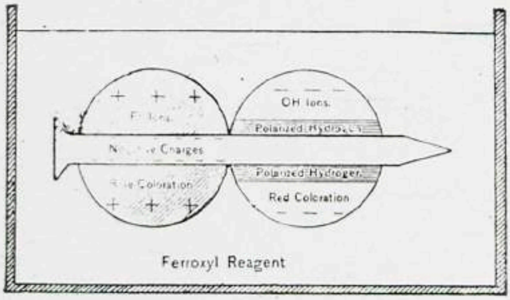


Illustration 4.



Diagrammatic explanation of action in ferroxyl indicator.

Illustration 5.

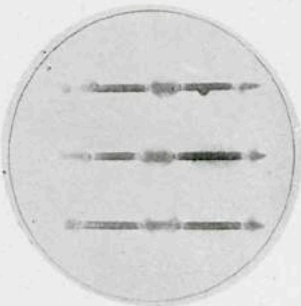


Illustration 6.

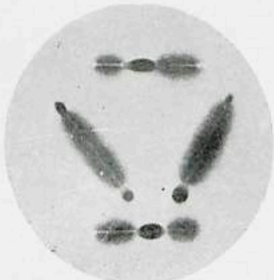


Illustration 7.

Illustration 8.

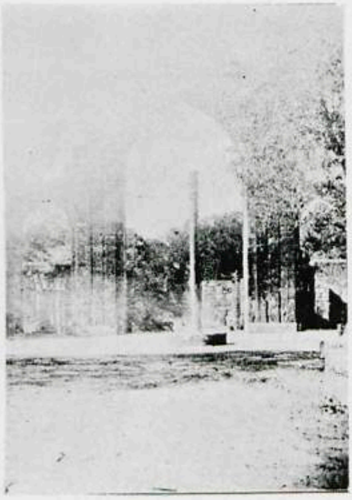


Illustration 9.

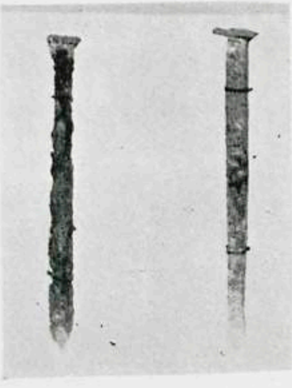


Illustration 10.

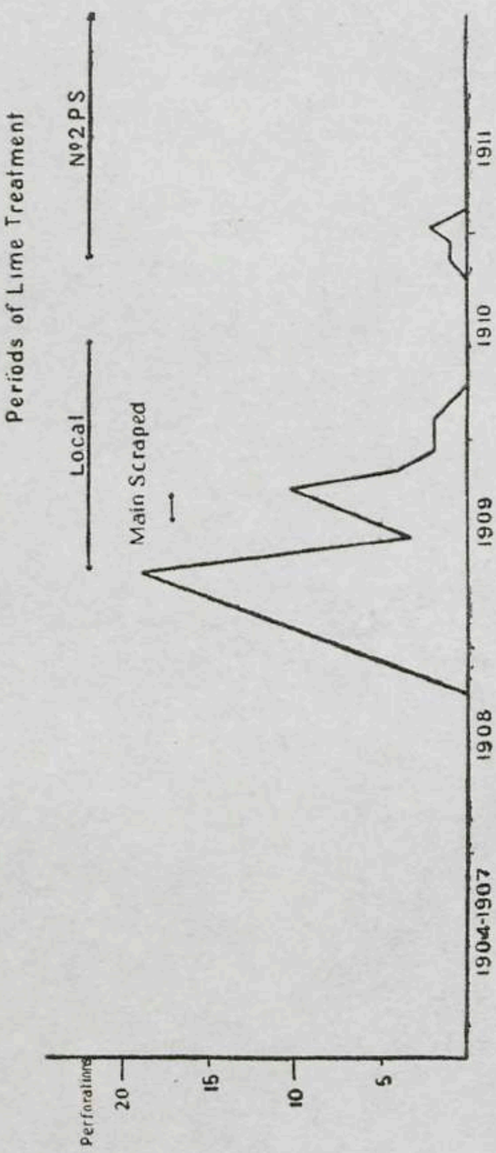


Illustration II.

WALLESLEY EMBANKMENT,
CHESHIRE.

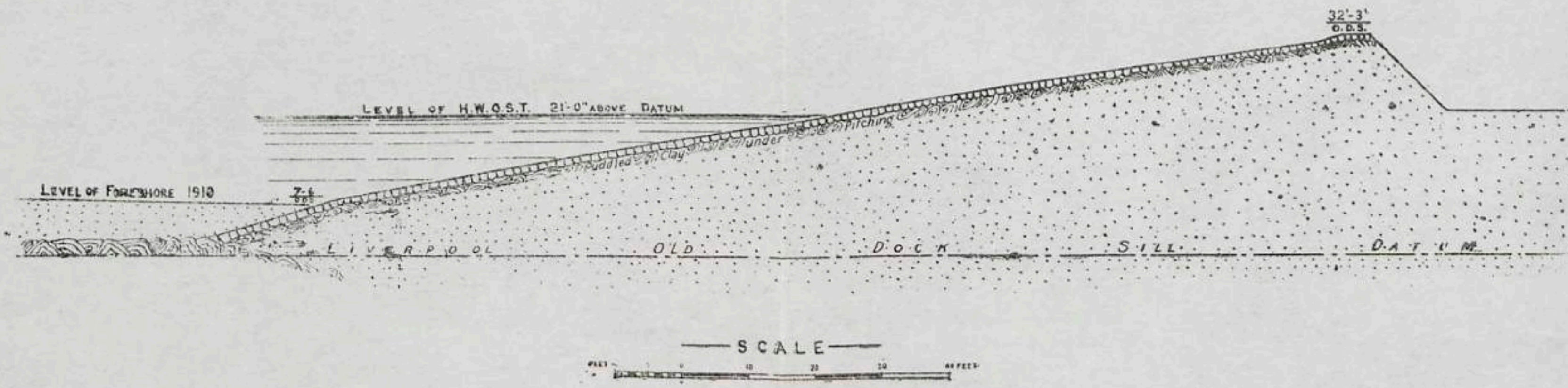


Fig. 1.

NEW WALLESLEY EMBANKMENT,
CHESHIRE.

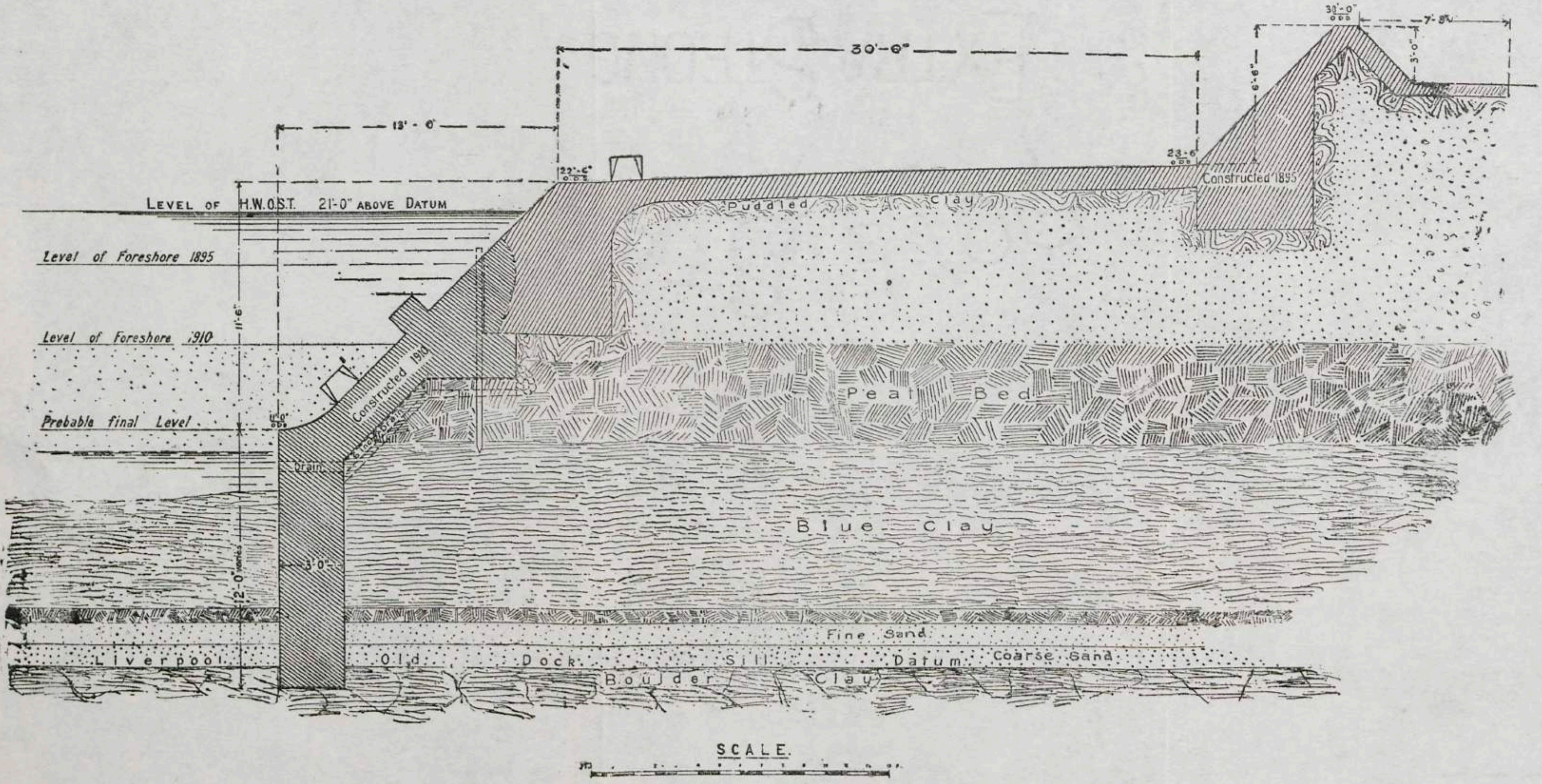


Fig. 2.

SEA WALL, SCARBOROUGH,
YORKSHIRE.

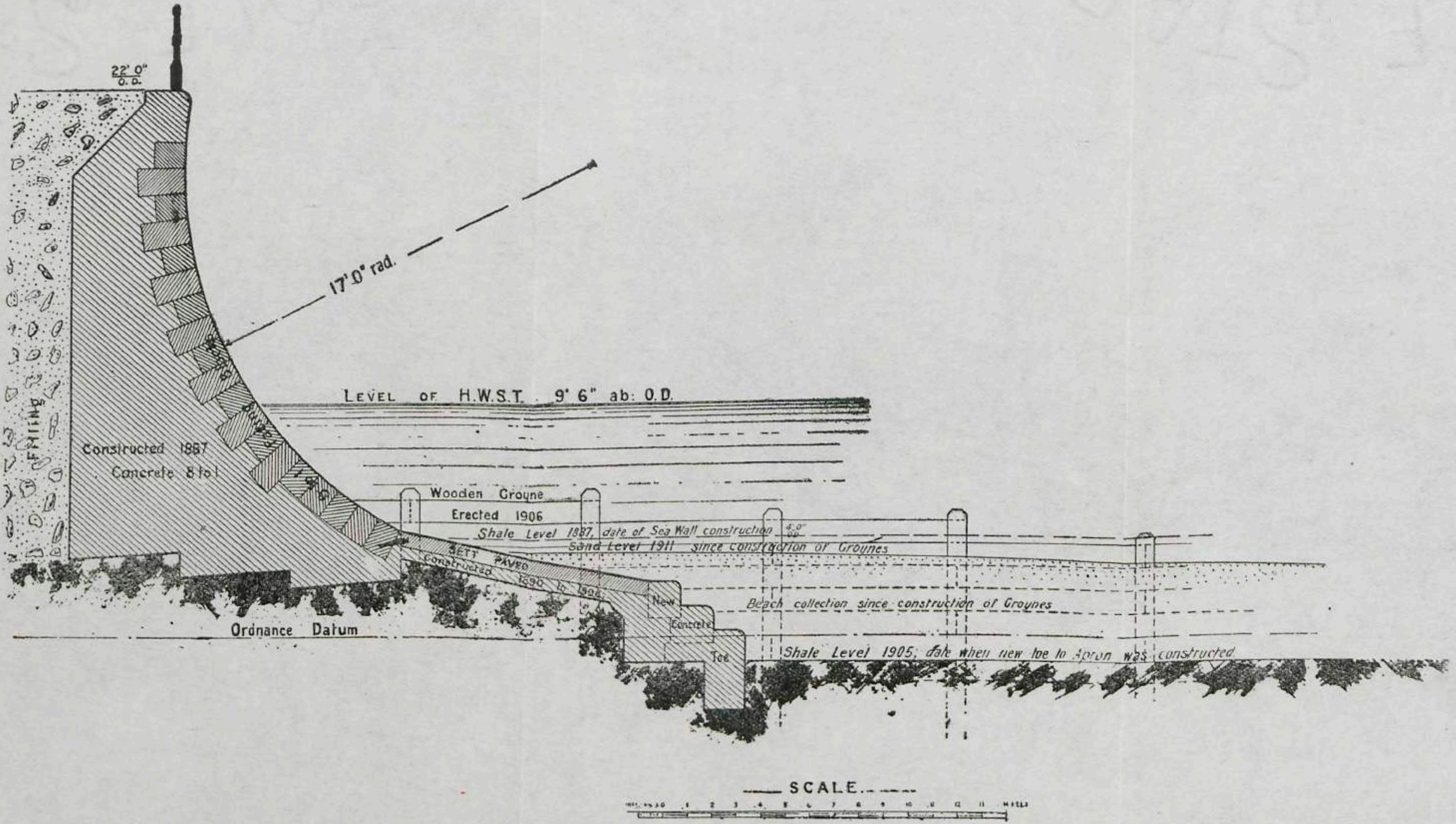


Fig. 3.

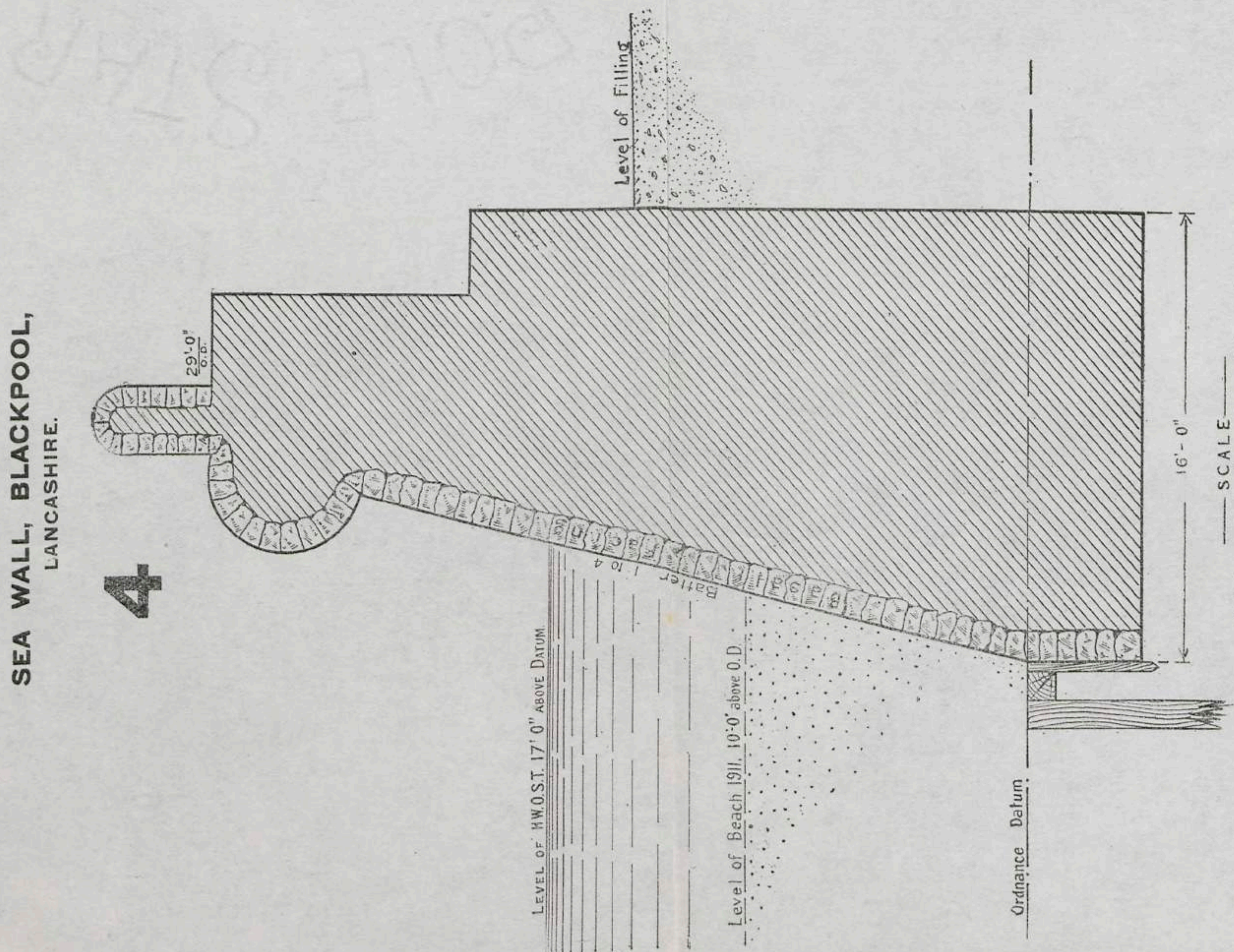

SEA WALL, BLACKPOOL,
LANCASHIRE.
4
29'-0" O.D.
Level of Filling
Batter 1 to 4
LEVEL OF H.W.O.S.T. 17' 0" ABOVE DATUM.
Level of Beach 1911, 10'-0" above O.D.
Ordnance Datum
16'-0"
SCALE

Fig. 4.

SEA WALL, HORNSEA, YORKSHIRE.

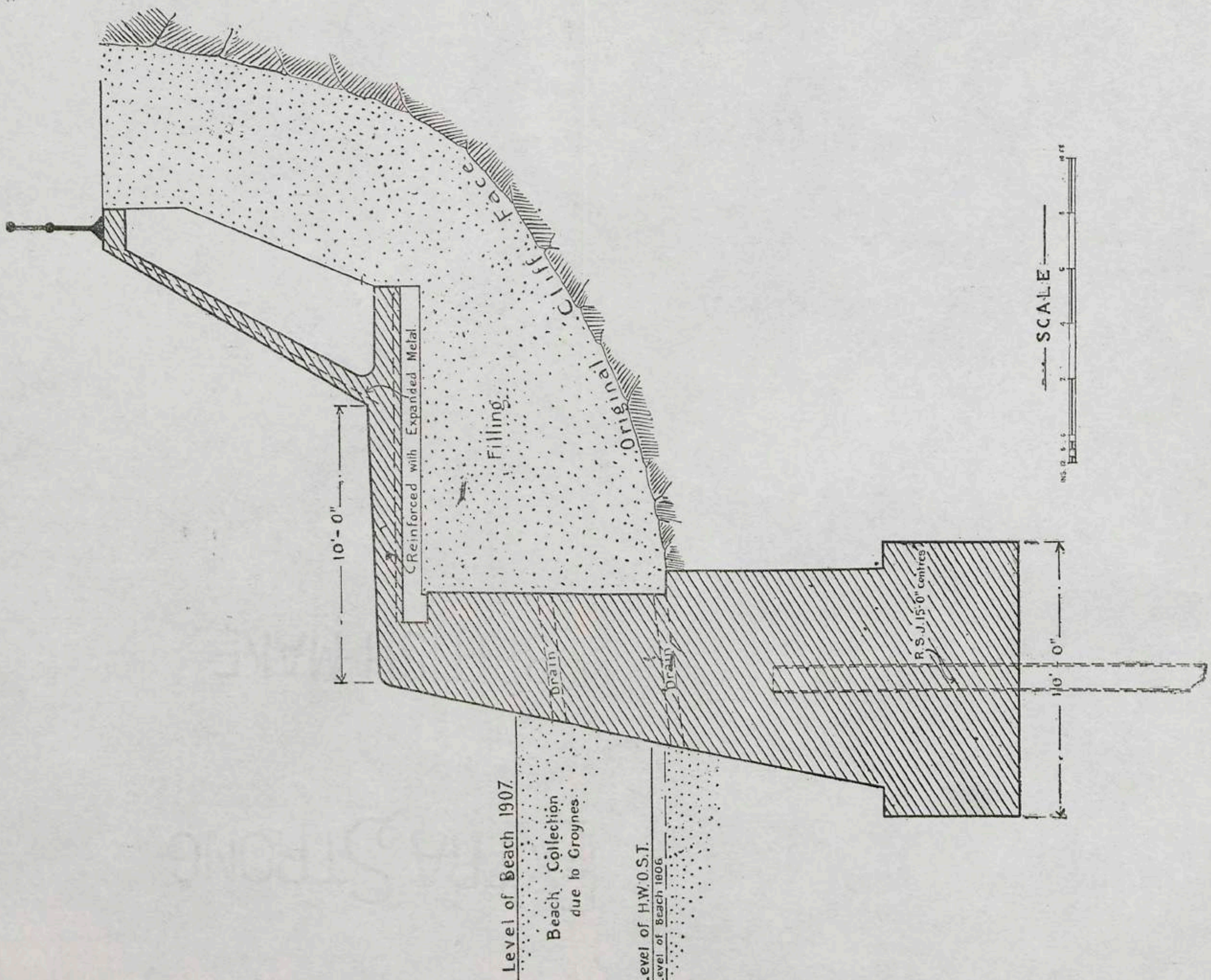
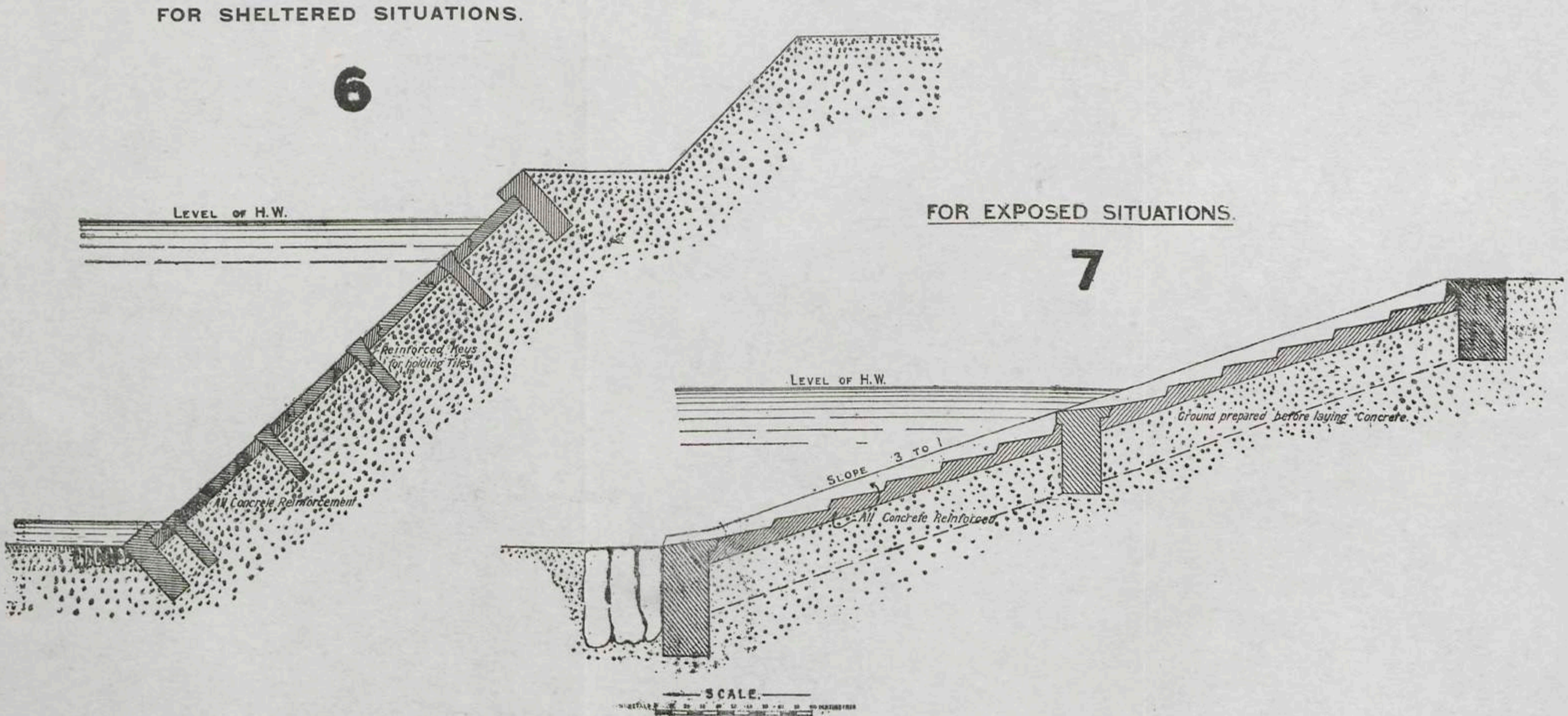


Fig. 5.

DE MURALT'S SYSTEM OF REINFORCEMENT FOR SEA DEFENCES.



Figs. 6 and 7.

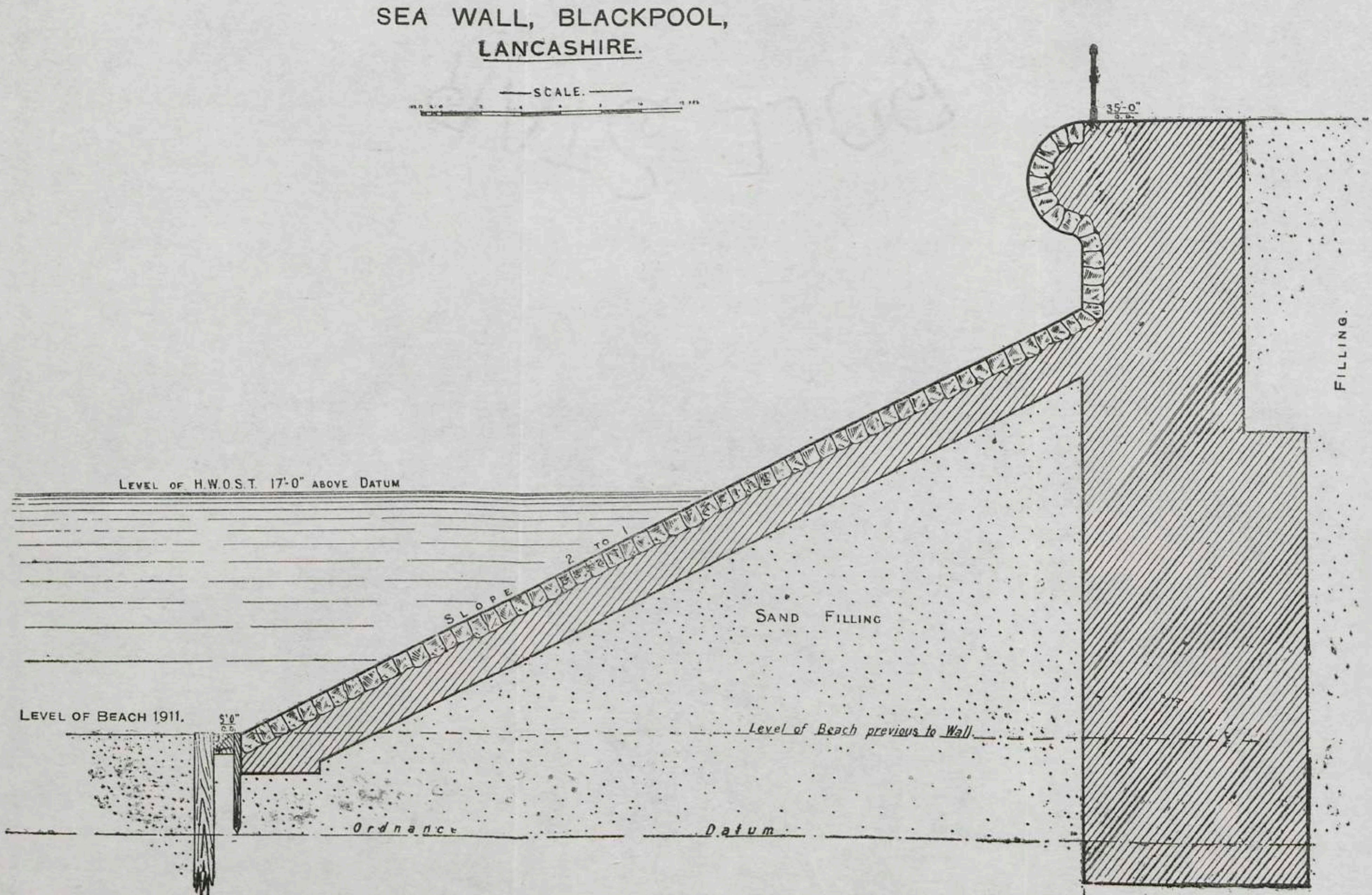

SEA WALL, BLACKPOOL,
LANCASHIRE.
SCALE.
35'-0"
O.D.
FILLING.
Level of H.W.O.S.T. 17'-0" above Datum
Slope 2 to 1
Sand Filling
Level of Beach 1911.
5'-0"
O.D.
Level of Beach previous to Wall.
Ordnance Datum
11'-0"

Fig. 8.

SECTIONS OF CLAY BANK.

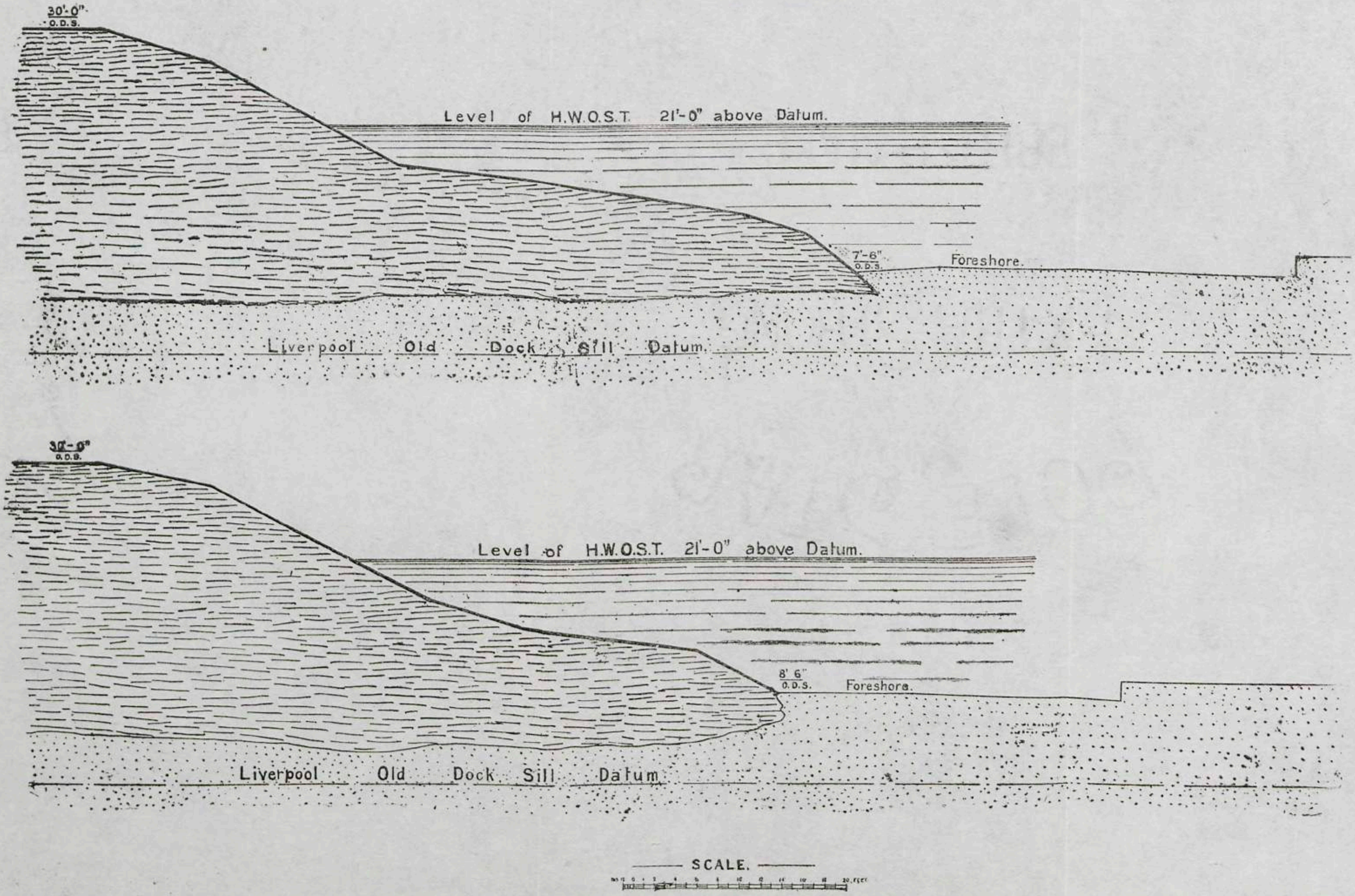


Fig. 9.

Plate 1.

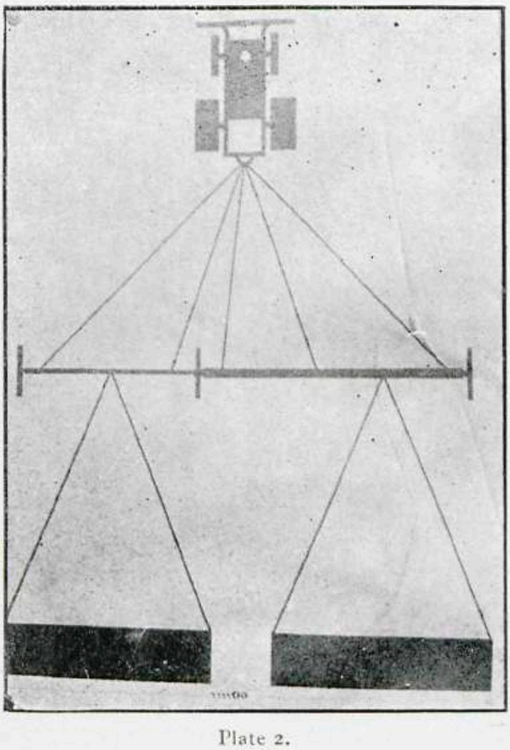


Plate 2.

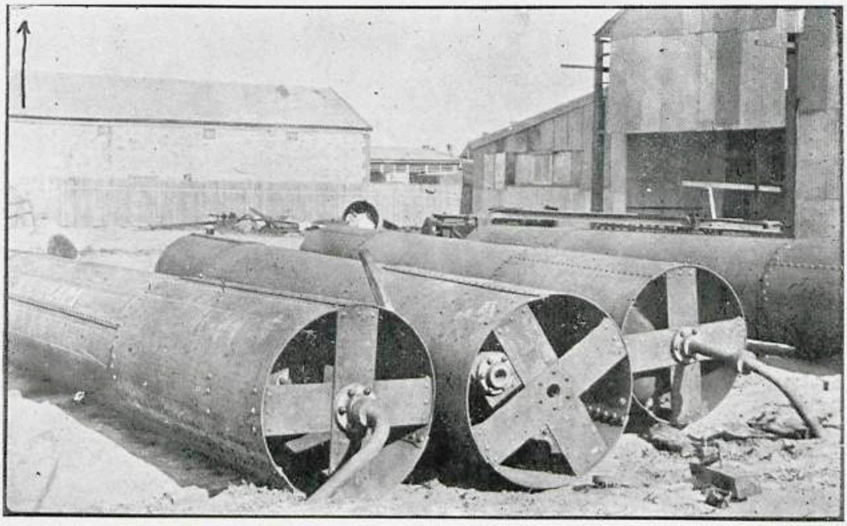
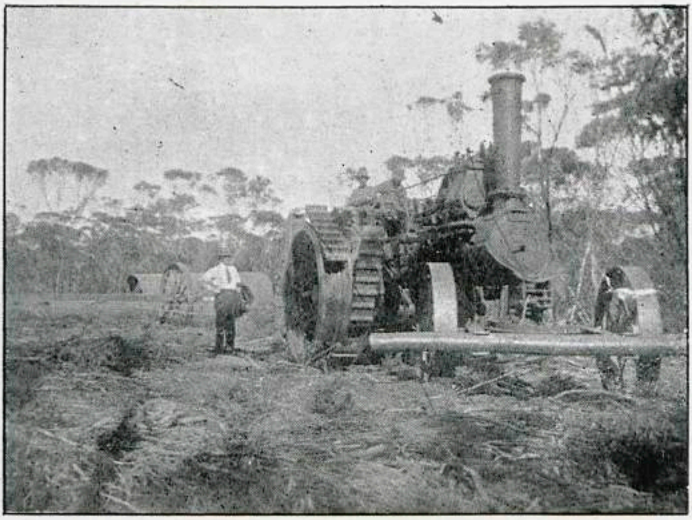


Plate 3.



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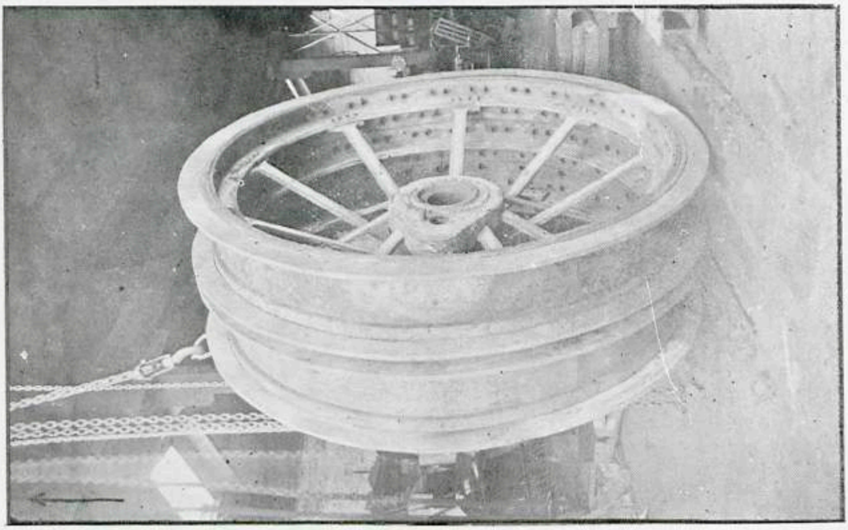
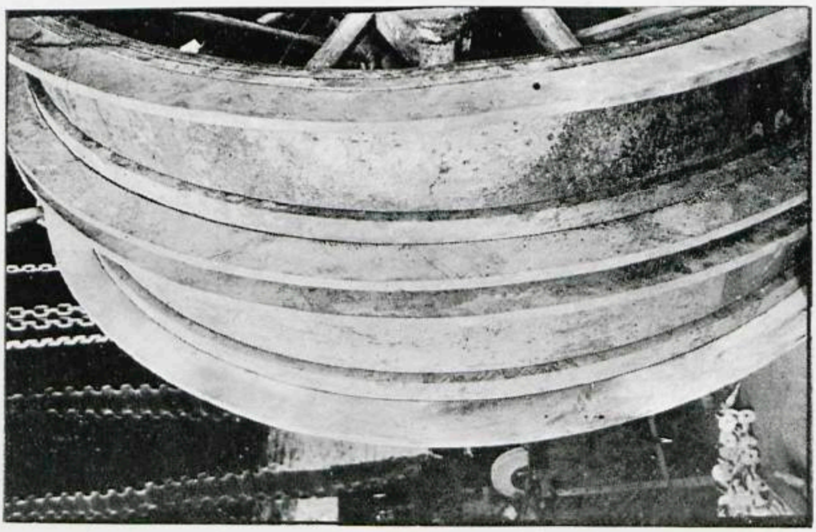


Plate 5



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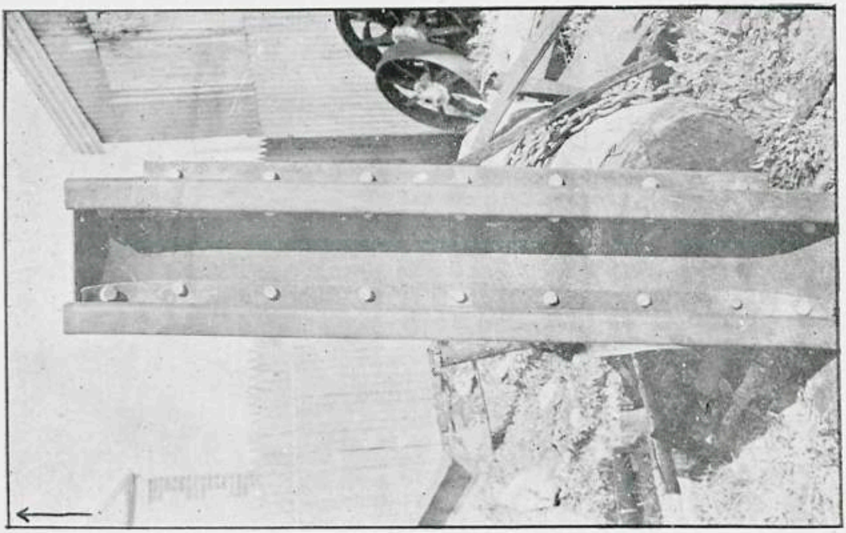
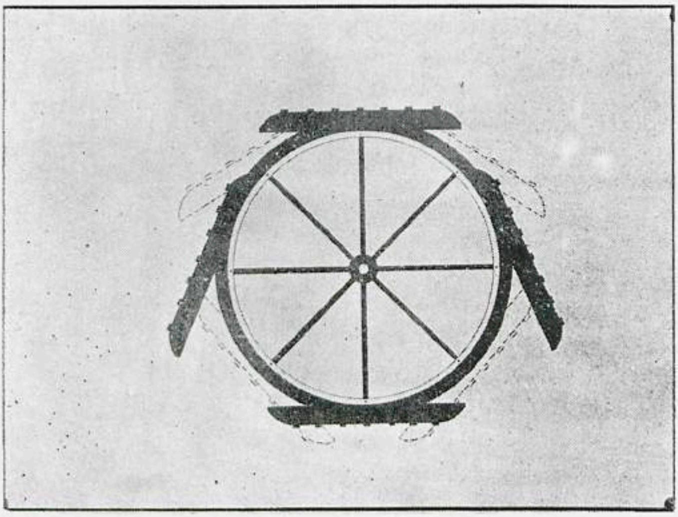


Plate 7.

Plate 8.



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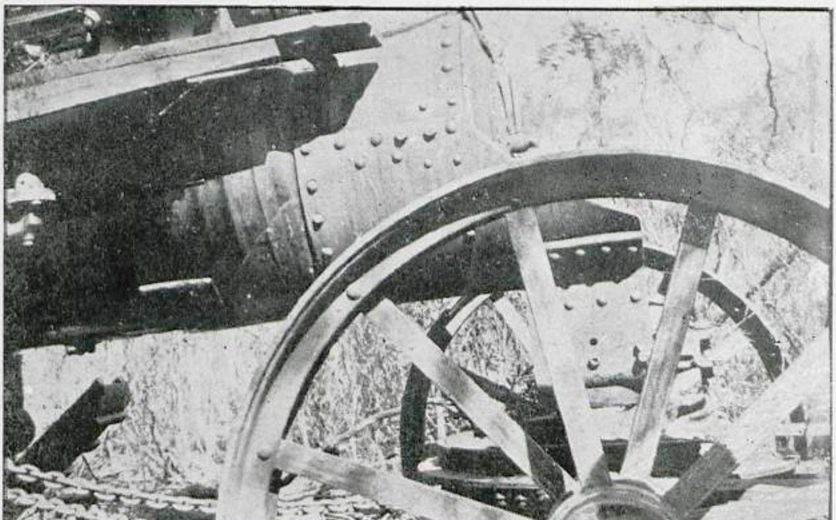
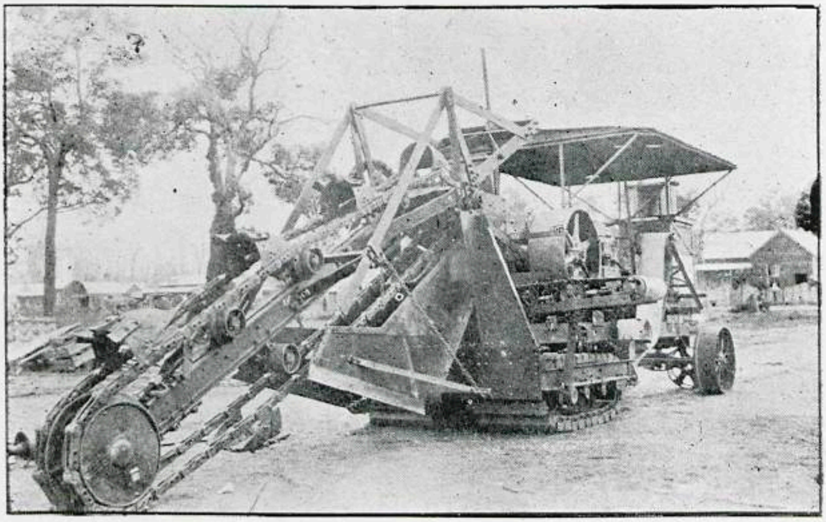


Plate 10.

Plate 11.

Plate 12.



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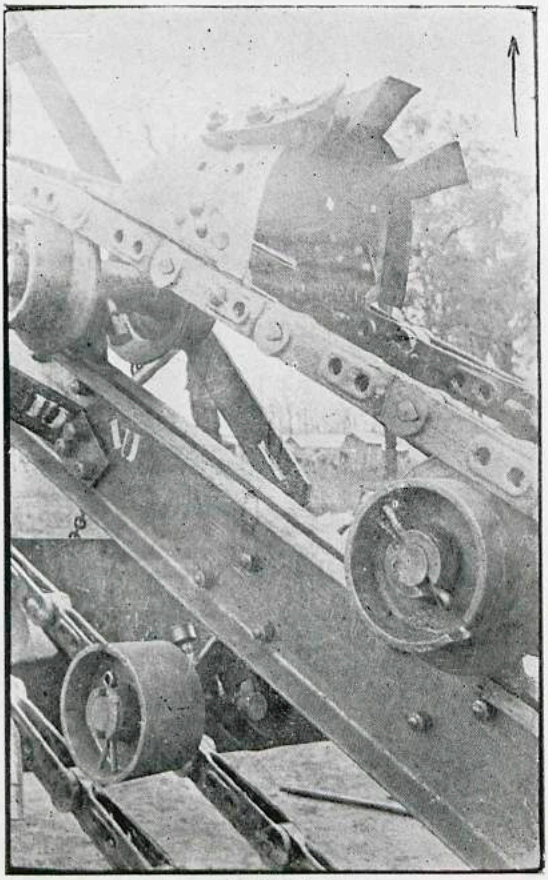

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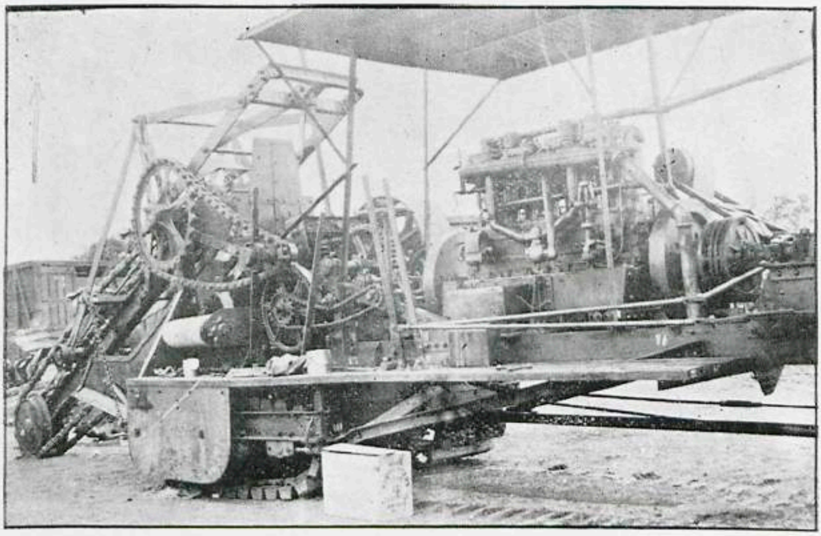
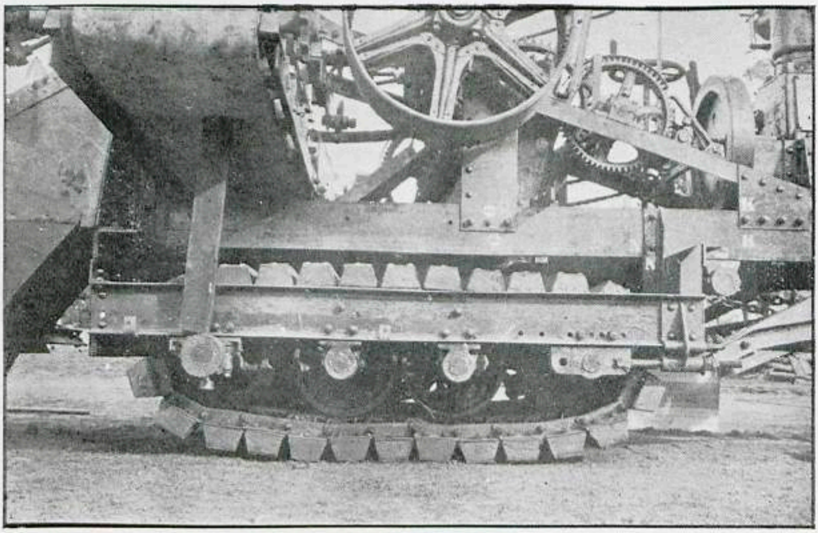


Plate 15.



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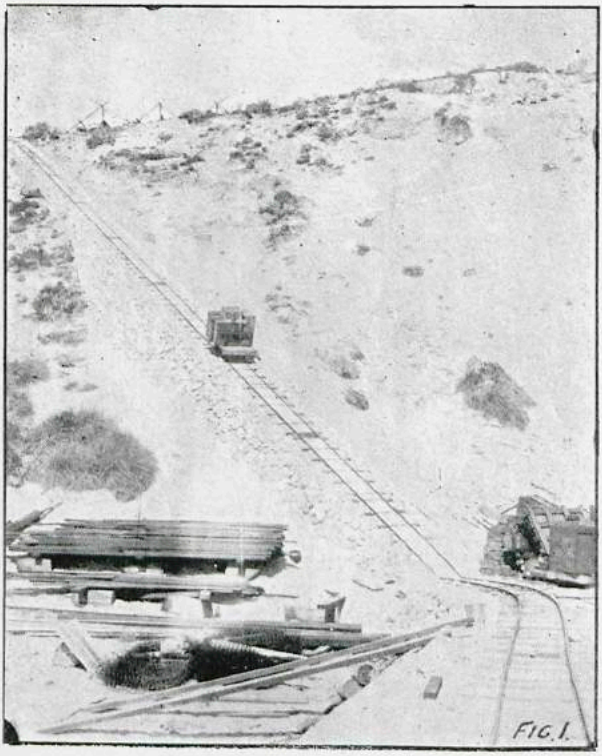


Fig. 1.

Fig. 2.

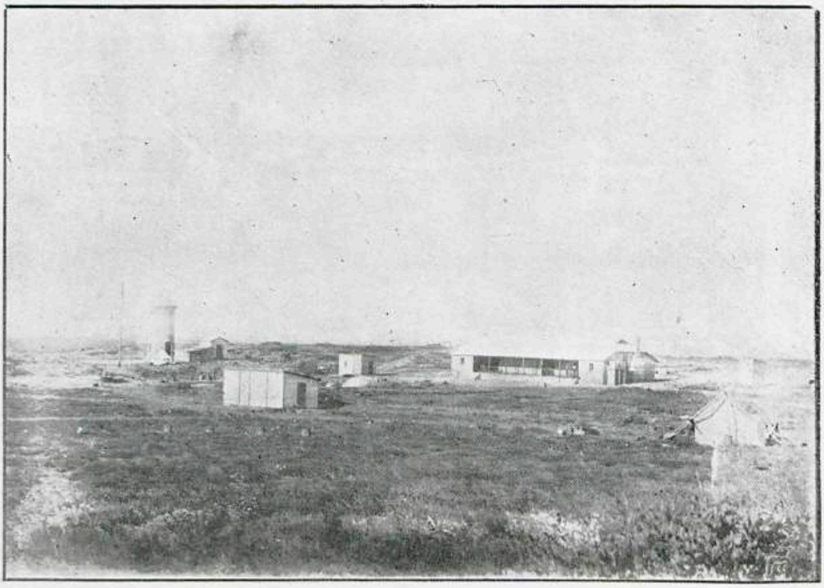
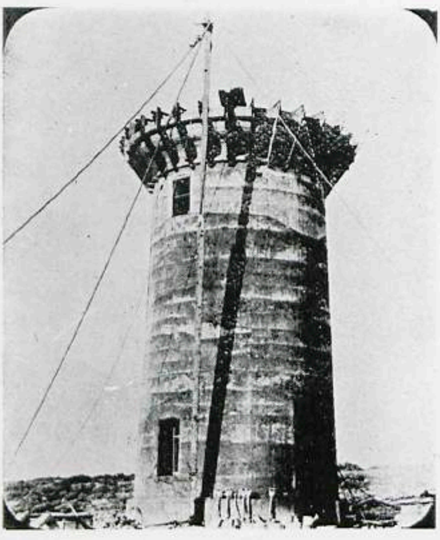


Fig. 3.



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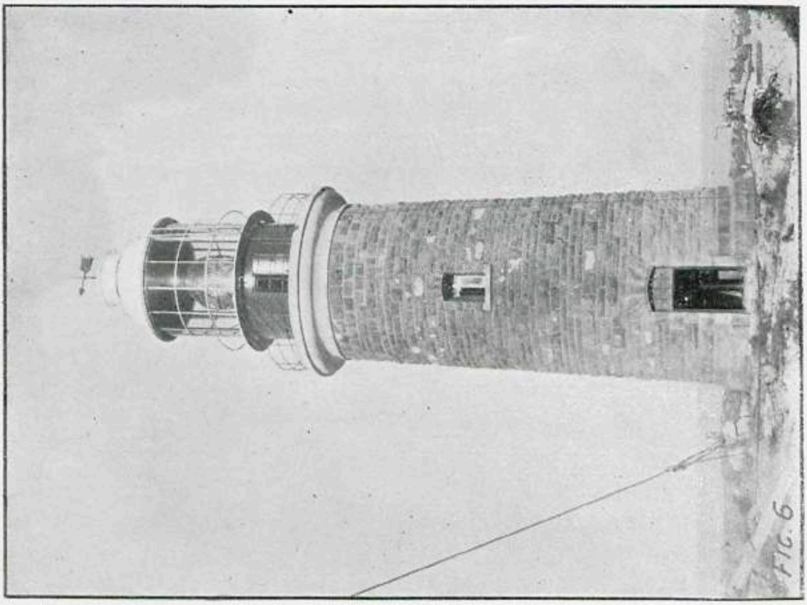

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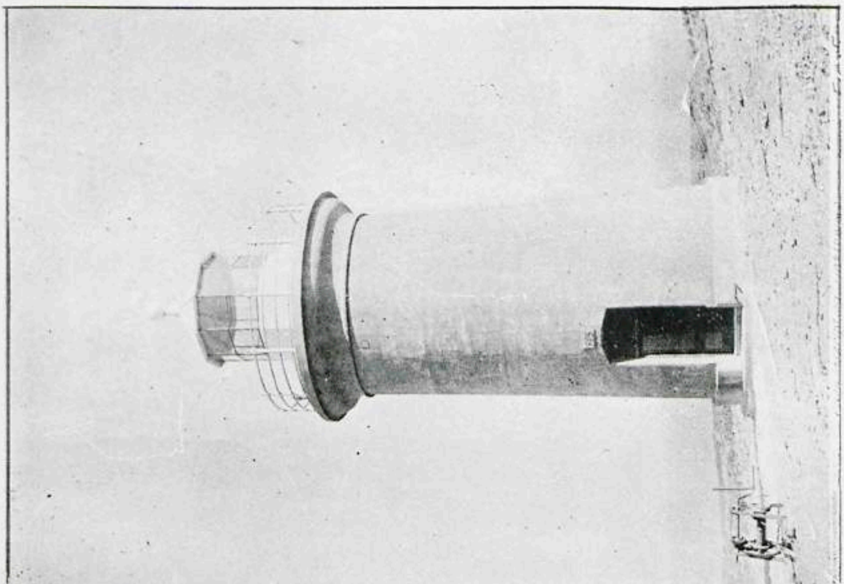

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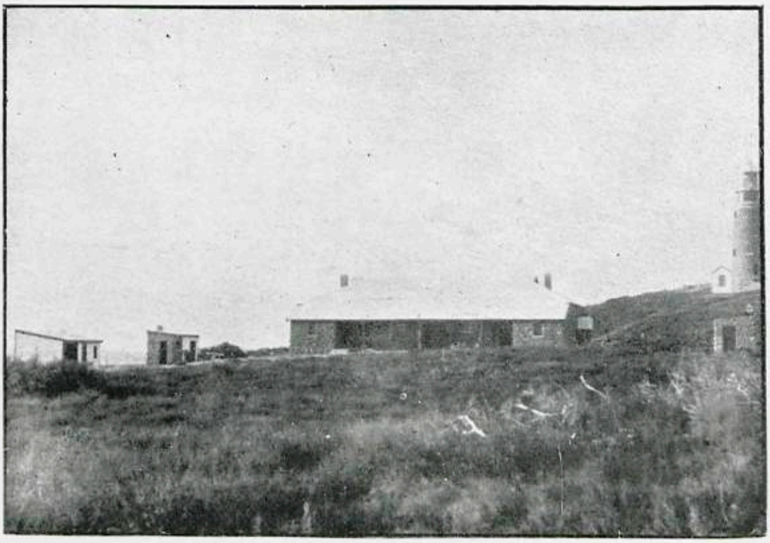

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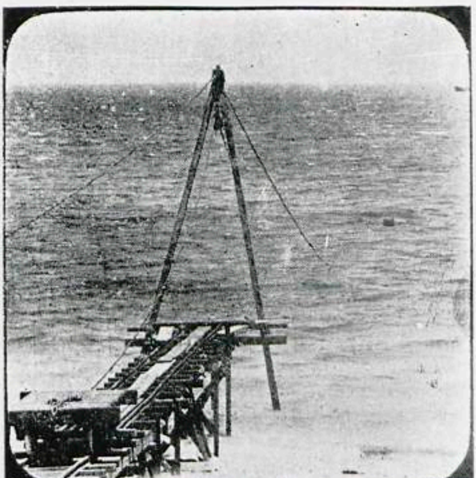

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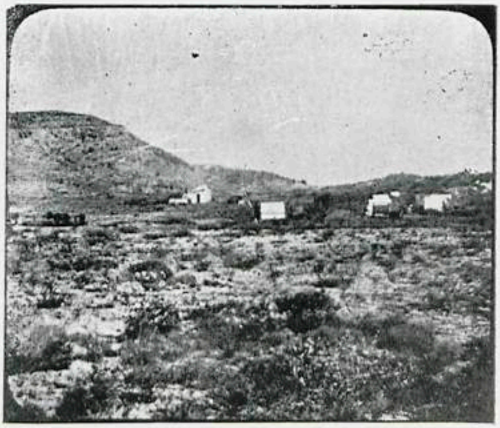
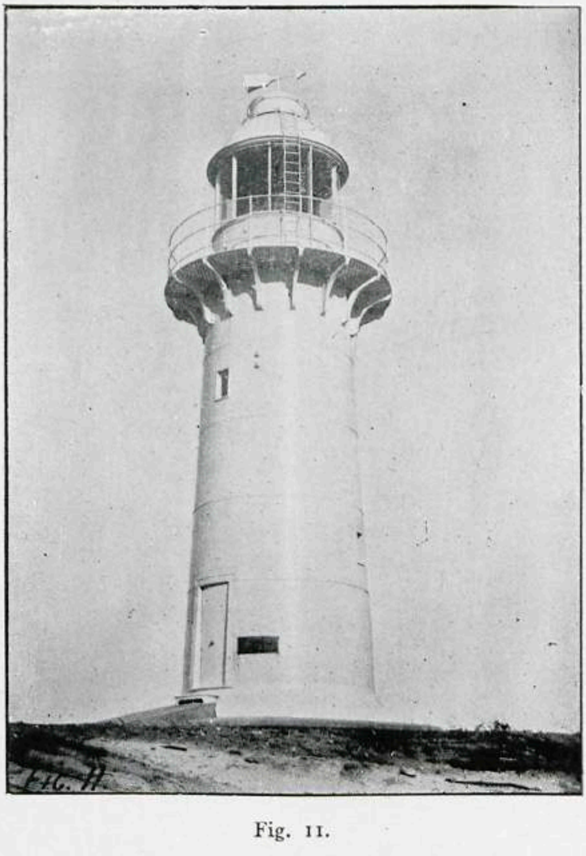


Fig. 9.

Fig. 10.



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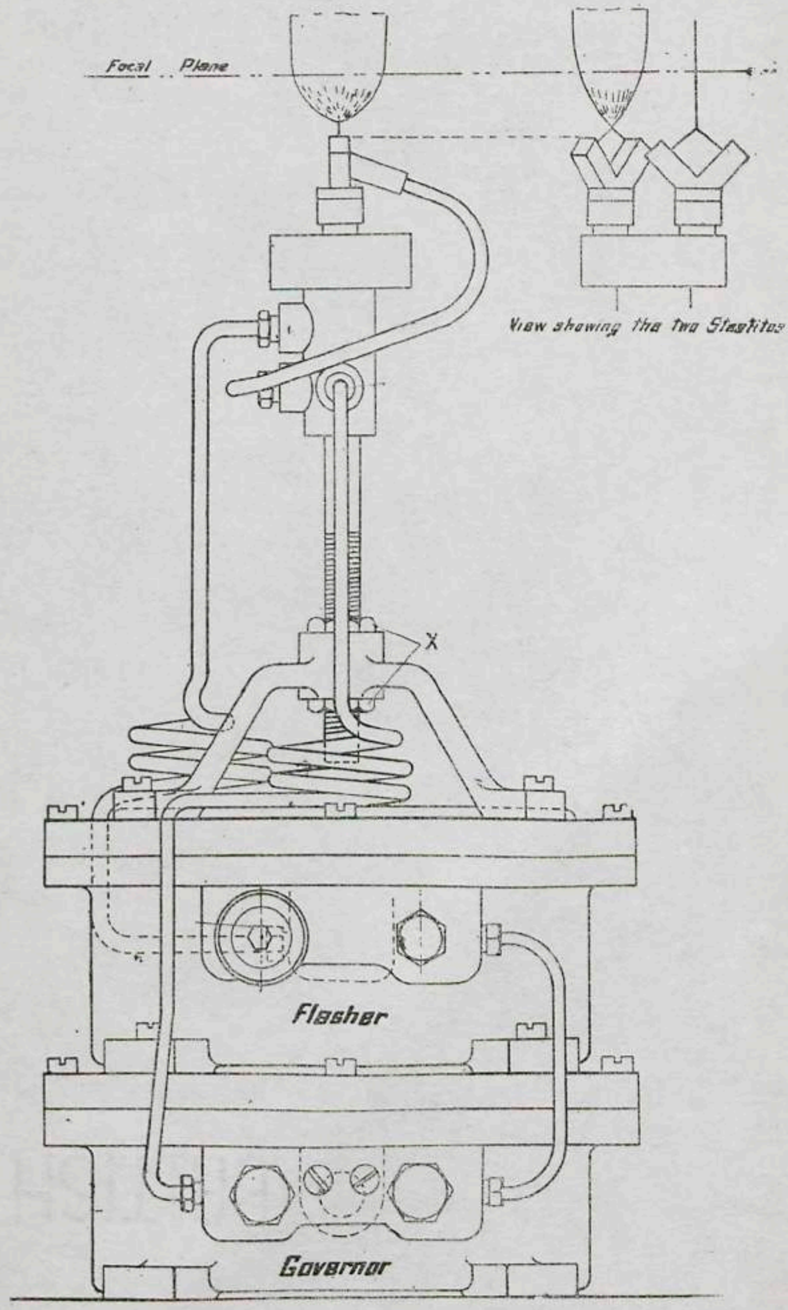
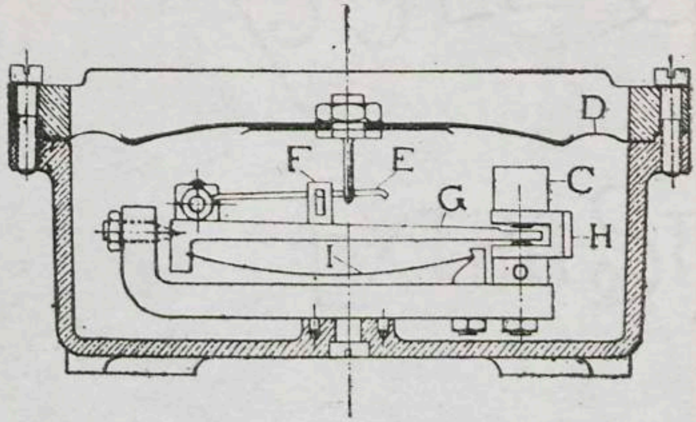
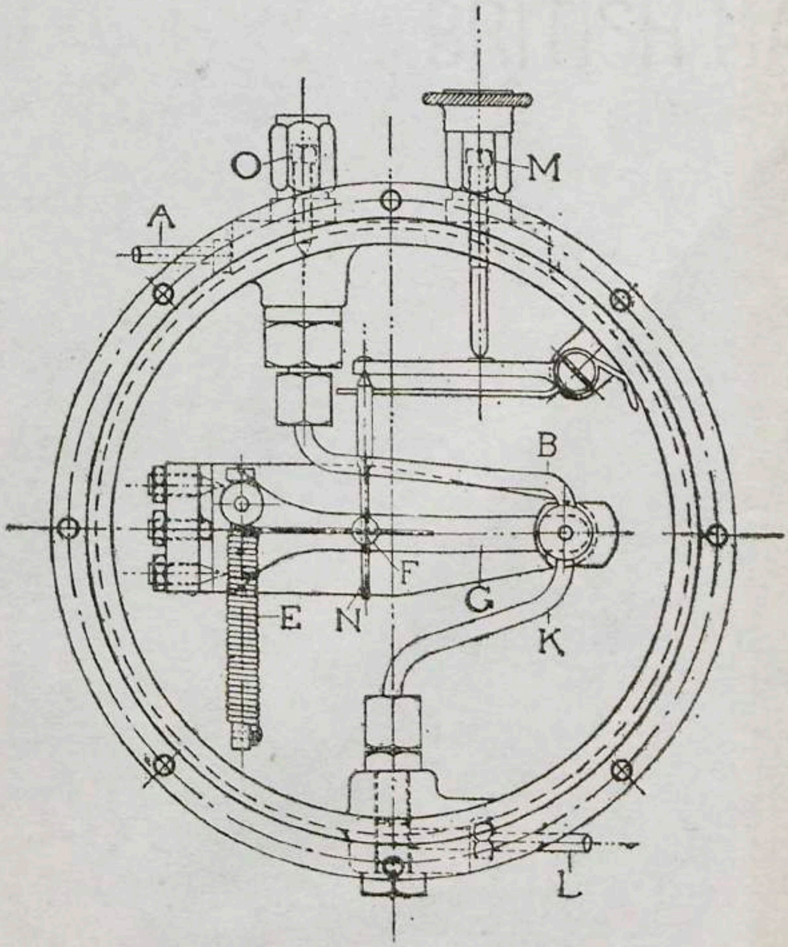


Part of Fig. 14.

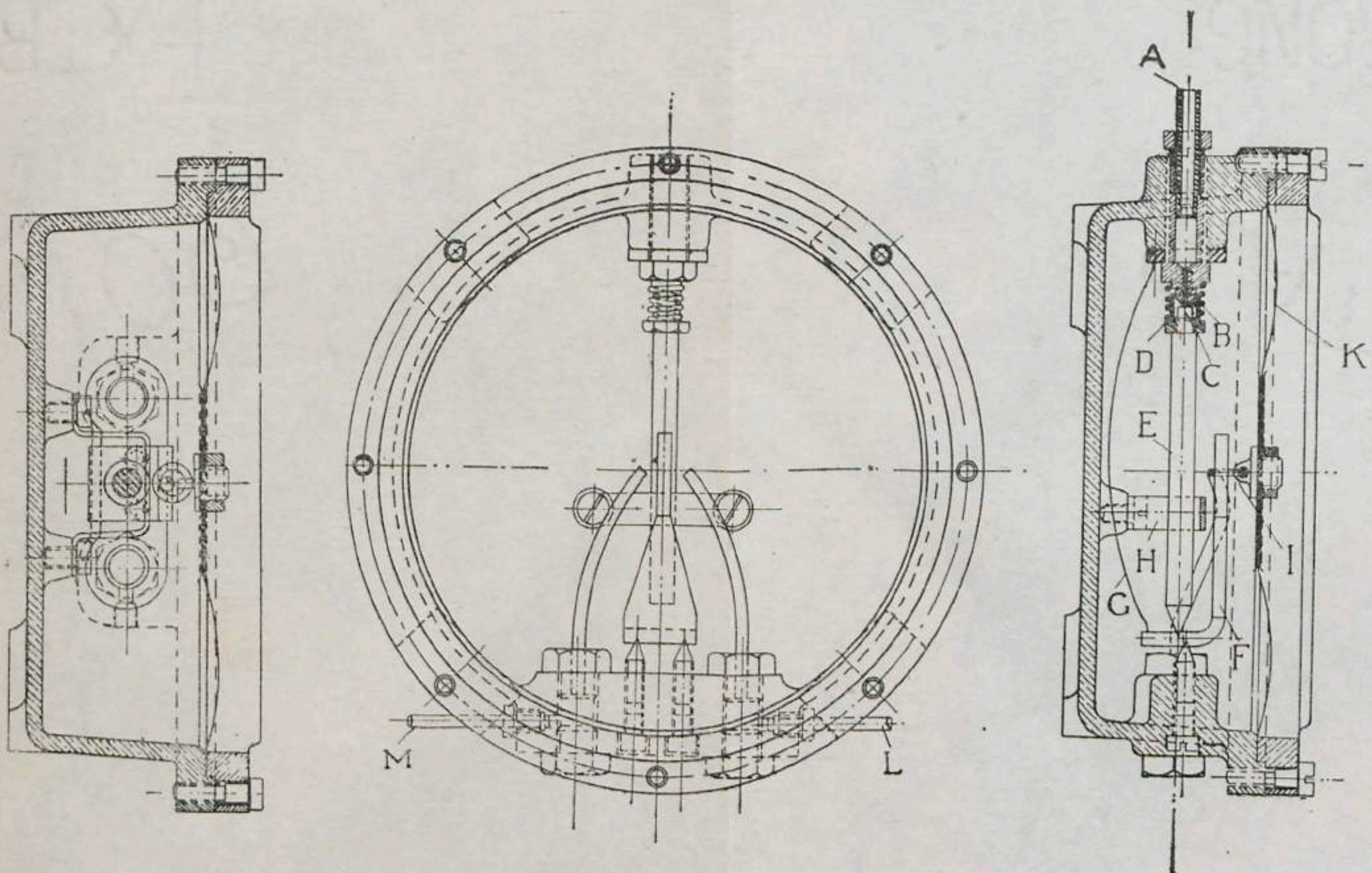
APPARATUS COMPLETE.





Part of Fig. 14.

GOVERNOR.



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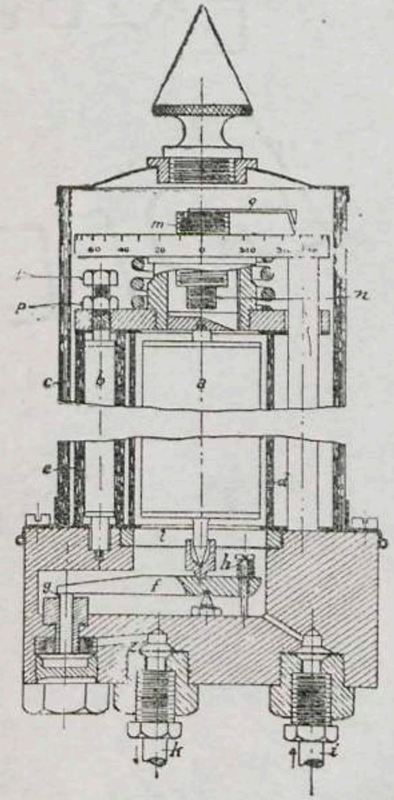

Sun Valve

Fig. 15.

V. K. JONES & CO.,
PRINTERS,
859-861 Hay Street, Perth.